Teton River Subbasin Assessment And Total Maximum Daily Load

Photo courtesy of Timothy Randle, Bureau of Reclamation

Department of Environmental Quality

January 10, 2003

WATER QUALITY CONCERNS IN THE TETON SUBBASIN

Water Quality Standards

Water quality standards are legally enforceable rules consisting of three parts: designated uses of waters, numeric or narrative criteria to protect those uses, and an antidegradation policy. Each state has authority to develop water quality standards with guidance and oversight from EPA. Any state that fails to issue standards adequate to achieve the goals and purposes of the CWA is subject to federal water quality standards promulgated by EPA (Adler 1995). Idaho's water quality standards are published as section 58.01.02 of Idaho's administrative rules (*IDAPA 58.01.02 - Water Quality Standards and Wastewater Treatment Requirements*).

Designated Uses The beneficial uses for which the surface waters of Idaho are to be protected are defined in the following excerpt from IDAPA 58.01.02.100:

01. Aquatic Life.

a. Cold water: water quality appropriate for the protection and maintenance of a viable aquatic life community for cold water species.

b. Salmonid spawning: waters which provide or could provide a habitat for active self-propagating populations of salmonid fishes.

c. Seasonal cold water: water quality appropriate for the protection and maintenance of a viable aquatic life community of cool and cold water species, where cold water aquatic life may be absent during, or tolerant of, seasonally warm temperatures.

d. Warm water: water quality appropriate for the protection and maintenance of a viable aquatic life community for warm water species.

e. Modified: water quality appropriate for an aquatic life community that is limited due to one or more conditions set forth in 40 CFR 131.10(g) which preclude attainment of reference streams or conditions.

02. Recreation.

a. Primary contact recreation: water quality appropriate for prolonged and intimate contact by humans or for recreational activities when the ingestion of small quantities of water is likely to occur. Such activities include, but are not restricted to, those used for swimming, water skiing, or skin diving.

b. Secondary contact recreation: water quality appropriate for recreational uses on or about the water and which are not included in the primary contact category. These activities may include fishing, boating, wading, infrequent swimming, and other activities where ingestion of raw water is not likely to occur.

Natural and Recreational Waterways

1. ***Teton River:** Trail Creek to Highway 33*
   (14 miles)
2. ***Fox Creek:** Springs to mouth*
   (2.5 miles)
3. ***Teton Creek:** Springs near Highway 33 to mouth*
   (3 miles)
4. ***Teton River:** Highway 33 to Felt Dam*
   (11 miles)
5. ***Badger Creek:** Springs to mouth*
   (3 miles)
6. ***Bitch Creek:** Idaho border to railroad trestle*
   (5 miles)
7. ***Bitch Creek:** Railroad trestle to Highway 32*
   (2 miles)
8. ***Bitch Creek:** Highway 32 to mouth*
   (7.5 miles)

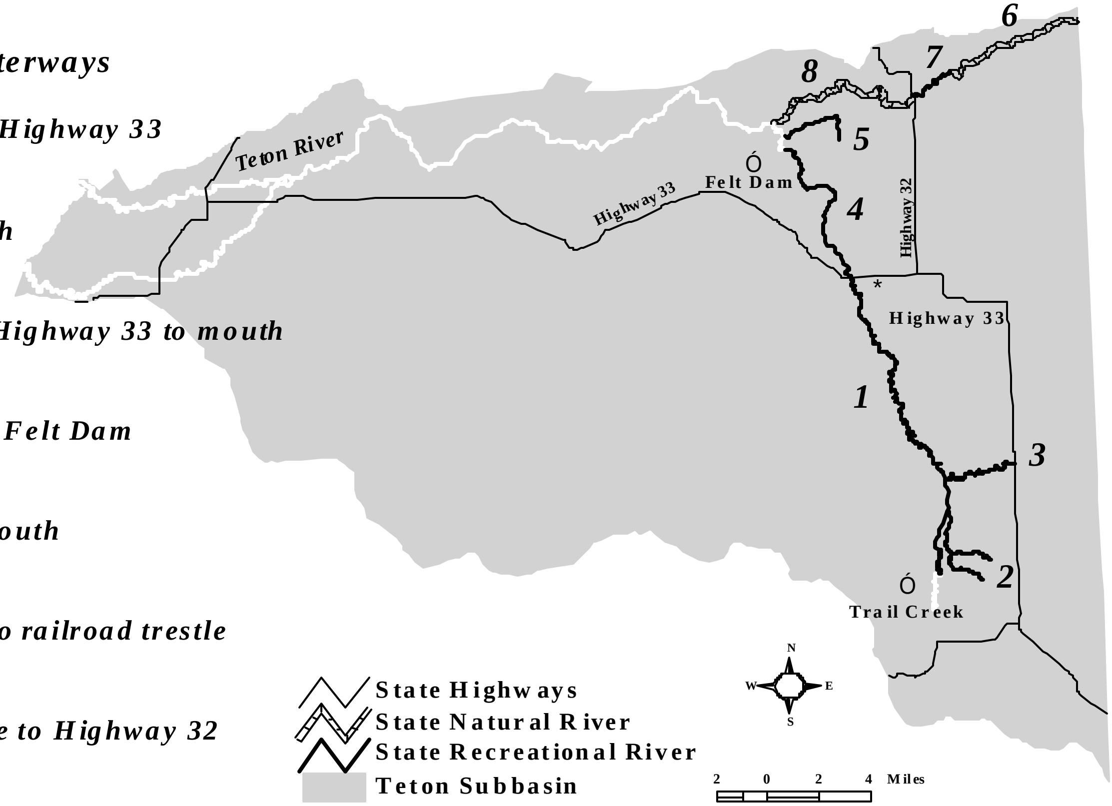

Figure 12. Stream segments designated as State Natural and State Recreational waters by the Idaho Water Resource Board (IWRB 1992).

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03. Water Supply.

a. Domestic: water quality appropriate for drinking water supplies.

b. Agricultural: water quality appropriate for the irrigation of crops or as drinking water for livestock. This use applies to all surface waters of the state.

c. Industrial: water quality appropriate for industrial water supplies. This use applies to all surface waters of the state.

04. Wildlife Habitat. Water quality appropriate for wildlife habitats. This use applies to all surface waters of the state.

05. Aesthetics. This use applies to all surface waters of the state.

The phrase, “this use applies to all surface waters of the state,” indicates that the beneficial use is *designated* for all surface waters and, conversely, that all surface waters are *designated* for protection of that particular beneficial use. For example, the water quality standards specify that the beneficial uses of agricultural water supply, industrial water supply, wildlife habitat, and aesthetics apply to all surface waters of the state, so all surface waters of the state are designated for those uses.

According to Section 39-3604 of Idaho Code, the beneficial uses of the surface waters of the state must be designated and specifically listed in the rules of the Department of Environmental Quality. Designations of the beneficial uses of most of the state’s major rivers, lakes, and reservoirs were incorporated into Idaho’s water quality standards in 1998. Section 58.01.02.150 lists the designations of the major surface waters in the Upper Snake hydrologic basin, and includes designations for the entire Teton River, including the North and South Forks. The North and South Forks of the Teton River are designated for cold water aquatic life, salmonid spawning, and secondary contact recreation. The mainstem of the river is designated for cold water aquatic life, salmonid spawning, primary contact recreation, drinking water supply, and Special Resource Water (Table 12). Although the mainstem is designated a drinking water supply, there are no community drinking water systems currently using the Teton River as a source, and although some households may use Teton River water for domestic purposes such as drinking, cooking, and bathing, such users have not been documented. A Special Resource Water is defined in the standards as a specific segment or body of water that is recognized as needing intensive protection to 1) preserve outstanding or unique characteristics; or 2) maintain a current beneficial use (IDAPA 58.01.02.003.96). The basis for designating the Teton River a Special Resource Water is documented in the *Comprehensive State Water Plan, Henry’s Fork Basin*, published in 1992 by the IWRB.

Table 12. Excerpt of *IDAPA 58.01.02 - Water Quality Standards and Wastewater Treatment Requirements*, showing surface waters in the Teton Subbasin for which beneficial uses have been designated.

Unit	Waters	Aquatic Life[1]	Recreation[2]	Other[3]
US-1	South Fork Teton River - Teton River Forks to Henry's Fork	COLD SS	SCR	
US-2	North Fork Teton River - Teton River Forks to Henry's Fork	COLD SS	SCR	
US-3	Teton River - Teton Dam to Teton River Forks	COLD SS	PCR	DWS SRW
US-4	Teton River - Canyon Creek to Teton Dam	COLD SS	PCR	DWS SRW
US-17	Teton River - Milk Creek to Canyon Creek	COLD SS	PCR	DWS SRW
US-19	Teton River - Badger Creek to Milk Creek	COLD SS	PCR	DWS SRW
US-20	Teton River - Spring Creek to Badger Creek	COLD SS	PCR	DWS SRW
US-21	Teton River - Mahogany Creek to Spring Creek	COLD SS	PCR	DWS SRW
US-25	Teton River - Patterson Creek to Mahogany Creek	COLD SS	PCR	DWS SRW
US-27	Teton River - source to Patterson Creek	COLD SS	PCR	DWS SRW

[1]Aquatic life beneficial uses include cold water (COLD) and salmonid spawning (SS).
[2]Recreation beneficial uses include secondary contact recreation (SCR) and primary contact recreation (PCR).
[3]Other beneficial uses include drinking water supply (DWS) and Special Resource Water (SRW).

The beneficial uses of the majority of surface waters in the Teton Subbasin, which are not addressed in Table 12, are addressed in subpart 101 of the water quality standards, entitled "Nondesignated Surface Waters." This section states, "Prior to designation, undesignated waters shall be protected for beneficial uses, which includes all recreational use in and on the water and the protection and propagation of fish, shellfish, and wildlife, wherever attainable." This rule, and the aquatic life and recreation uses listed above, are intended to address the "fishable" and "swimmable" goals of the CWA. Subpart 101 also states that because most of Idaho's waters are presumed to support cold water aquatic life and primary or secondary contact recreation, criteria to protect these uses apply to all undesignated waters unless DEQ determines that other beneficial uses are more appropriate. For example, a stream fed by a warm spring may support a healthy, self-sustaining population of cold water fish despite temperatures that sometimes exceed criteria to protect cold water aquatic life. After reviewing relevant data, DEQ may determine that it is more appropriate to apply criteria that protect seasonal cold water aquatic life instead of criteria that protect cold water aquatic life.

Water Quality Criteria Water quality criteria specify the physical, chemical, and biological conditions that must be met to achieve and protect a designated use. Idaho's water quality criteria are organized into general surface water criteria, numeric criteria for toxic substances; surface water quality criteria for use designations; standards for waters discharged from dams, reservoirs, and hydroelectric facilities; and site-specific surface water quality criteria (Appendix E). *General Surface Water Criteria* (IDAPA 58.01.02.200) are narrative criteria specifying that the surface waters of the state shall be free from the following pollutants in concentrations found to impair beneficial uses: hazardous materials; toxic substances; deleterious materials; radioactive materials; floating, suspended, or submerged matter; excess nutrients; oxygen-demanding materials; and sediment. *Numeric Criteria for Toxic Substances for Waters Designated for Aquatic Life, Recreation, or Domestic Water Supply Use* (IDAPA 58.01.02.210) references the National Toxics Rule (40 CFR 131.36(b)(1)) and specifies the manner in which the rule is incorporated into Idaho's standards. *Surface Water Quality Criteria For Aquatic Life Use Designations* (IDAPA 58.01.02.250), *Surface Water Quality Criteria For Recreation Use Designations* (IDAPA 58.01.02.251), and *Surface Water Quality Criteria For Water Supply Use Designations* (IDAPA 58.01.02.252) specify numeric criteria protective of the stated use.

Aquatic life uses are protected by numeric criteria for pH, dissolved gas, total chlorine residual, dissolved oxygen, un-ionized ammonia, temperature, turbidity, and intergravel oxygen. Recreational uses are protected by limits on concentrations of the fecal bacterium, *E. coli*. Domestic water supplies are protected by limits on radioactive materials and turbidity. Water quality criteria for the beneficial uses of agricultural and industrial water supplies, wildlife habitats, and aesthetics are generally satisfied by general surface water criteria (IDAPA 58.01.02.252 and IDAPA 58.01.02.253). *Site-Specific Surface Water Quality Criteria* (IDAPA 58.01.02.275) describes the procedures for modifying criteria through site-specific analyses and confirms that site-specific criteria supersede criteria for specific use designations. And finally, *Dissolved Oxygen Standards for Waters Discharged from Dams, Reservoirs, and Hydroelectric Facilities* (IDAPA 58.01.02.276) specifies the concentrations of dissolved oxygen below existing facilities and below facilities where significant fish spawning occurs. Violations of water quality criteria constitute violations of water quality standards except under circumstances specified at 58.01.02.080 (Appendix E).

Antidegradation Policy Idaho's antidegradation policy (IDAPA 58.01.02.051) states that "existing instream water uses and the level of water quality necessary to protect existing uses shall be maintained and protected," and that the water quality of Outstanding Resource Waters "...shall be maintained and protected from the impacts of nonpoint source activities." The policy makes provisions for degradation when "...necessary to accommodate important economic or social development in the area in which the waters are located," though water quality must continue to support beneficial uses.

Water Quality Limited Segments A water quality-limited waterbody is defined by state statute as "...a water body identified by the Department, which does not meet applicable water quality standards, ...[and therefore] require[s] the development of a TMDL..." (IDAPA 58.01.02.003.115). When Idaho's TMDL development schedule was finalized in 1997, the waterbodies considered subject to TMDL development were those identified in Idaho's 1994 §303(d) list (EPA 1997). This list was promulgated by the EPA, as directed by the U.S. District Court for the Western District of Washington, after the court found that the list submitted by the state of Idaho and approved by the EPA was underinclusive (W.D. Wa. Slip op., April 14, 1996). The §303(d) list developed by the EPA was based on the following information provided by the state: a list of 62 waters originally submitted by Idaho, lists of stream segments of concern contained in Idaho Basin Status Reports, Idaho's 1992 § 305(b) report, forest plans developed by the U.S. Forest Service, and comments submitted by the public (EPA 1994).

1996 §303(d) List As required by the CWA, Idaho submitted a biennial revision of the §303(d) list to the EPA in 1996. The 1996 list was substantively identical to the 1994 list except that spelling, numbering, and boundary errors had been corrected. Information to support the listing of stream segments was obtained from the *1991 Upper Snake River Basin Status Report* (DEQ 1991) or the *1992 Idaho Water Quality Status Report* (DEQ 1992). Portions of these and other reports are discussed in Appendix F to explain how and why specific stream segments in the Teton Subbasin were included in Idaho's 1994 and 1996 §303(d) lists.

1998 §303(d) List To develop its 1998 §393(d) list, DEQ implemented a waterbody assessment process based on BURP data collected by the agency from 1994 through 1996 (DEQ 1996b). Two stream segments that appeared on the 1996 §303(d) list, Teton Creek and the South Fork Teton River, were assessed as fully supporting their beneficial uses and were removed from the 1998 list. Conversely, a stream segment that had not appeared on the 1996 §303(d) list, North Leigh Creek, was assessed as not supporting its beneficial uses and was added to the 1998 list (Table 13). These deletions and additions were approved by the Region 10 Office of EPA on May 1, 2000. For the purpose of developing the Teton Subbasin TMDL, waterbodies on the 1998 §303(d) list are addressed in this assessment. The locations of listed stream segments are shown in Figure 13.

Pollutants and Applicable Water Quality Criteria

The following pollutants were identified on the 1998 §303(d) list as responsible for, or contributing to, impaired water quality conditions in the Teton Subbasin: sediment, flow alteration, nutrients, habitat alteration, and thermal modification (i.e., temperature). Sediment was identified as a pollutant affecting nine stream segments, flow alteration affected five segments, nutrients and habitat alteration each affected three segments, and thermal modification (i.e., temperature) affected two segments (Table 13). A pollutant was not identified for North Leigh Creek, a stream that was added to the 1998 §303(d) list because it was assessed as water quality impaired using BURP data. Although the BURP assessment process can determine that a beneficial use is not supported, it cannot identify the pollutant responsible.

State water quality criteria that directly pertain to sediment, nutrients, and temperature are listed in Table 14. An exceedance of any criterion constitutes a violation of water quality standards except in the following circumstances: 1) when DEQ issues a short-term exemption for activities that are essential to the protection or promotion of public interest and are unlikely to cause long-term injury of beneficial uses, and 2) in the case of temperature, when the air temperature exceeds the ninetieth percentile of the seven-day average daily maximum temperature calculated over the historic record at the nearest weather reporting station (*IDAPA 58.01.02.080).* A criterion for turbidity is included among the criteria for sediment because sediment suspended in the water column is usually a major component of turbidity. Other state criteria that may indirectly pertain to a pollutant are shown in Appendix E.

There are no state water quality criteria that pertain to flow alteration or habitat alteration, and it is DEQ's policy that TMDLs will not be developed for these pollutants. Among the assumptions used to compile Idaho's 1998 §303(d) list, DEQ asserts that flow alteration and habitat alteration are 1) not defined by the CWA as pollutants, and 2) unsuitable for TMDL development (DEQ 1998b). The capacity of a waterbody to support aquatic life is initially determined by the presence of water and secondarily by the quality of that water. However, the relationship between flow apportionment and water quality is clearly addressed in Idaho's water quality standards (IDAPA 58.01.02.050.01) as follows:

> The adoption of water quality standards and the enforcement of such standards is not intended to conflict with the apportionment of water to the state through any of the interstate compacts or decrees, or to interfere with the rights of Idaho appropriators, either now or in the future, in the utilization of the water appropriations which have been granted them under the statutory procedure...

Table 13. Excerpt of the 1998 §303(d) list showing water quality impaired waterbodies in the Teton Subbasin.

Waterbody	WQLS[1] Number	Boundaries	Pollutant(s)	Stream Miles
Badger Creek	2125	Highway 32 to Teton River[2]	Sediment	8.51
Darby Creek	2134	Highway 33 to Teton River	Sediment Flow alteration	3.48
Fox Creek	2136	Wyoming Line to Teton River	Sediment Temperature[3] Flow alteration	9.18
Horseshoe Creek	2130	Confluence of North and South Forks to Teton River[4]	Flow alteration	7.03
Moody Creek	2119	Forest boundary to Teton River	Nutrients	25.38
North Leigh Creek	5230	Wyoming line to Spring Creek	Unknown[5]	4.90
Packsaddle Creek	2129	Headwaters to Teton River	Sediment Flow alteration	9.88
South Leigh Creek	2128	Wyoming line to Teton River	Sediment	11.30
Spring Creek	2127	Wyoming line to Teton River	Sediment Temperature Flow alteration	12.60
Teton River (Teton Valley Segment)	2116	Highway 33 to Bitch Creek	Sediment Habitat alteration Nutrients	10.10
Teton River	2118	Headwaters to Trail Creek	Habitat alteration	2.65
Teton River	2117	Trail Creek to Highway 33	Sediment Habitat alteration	20.00
North Fork Teton River	2113	Forks to Henry's Fork, Snake River	Sediment Nutrients	14.64

[1]WQLS: Water quality limited segment. The last three digits of this number correspond to the Pacific Northwest Rivers Study number used in the 1996 §303(d) list to identify segments.
[2]The boundaries of Badger Creek were shown as "R45ET6NS10 to first tributary" on the 1996 list. This change reduced the listed distance of Badger Creek by 3.83 stream miles.
[3]The pollutant, "Temperature," was shown "Thermal alteration" on the 1996 list.
[4]The change in boundaries of Horseshoe Creek from the 1996 list is an apparent clerical error.
[5]A pollutant was not identified for segments assessed as water quality impaired using BURP data.

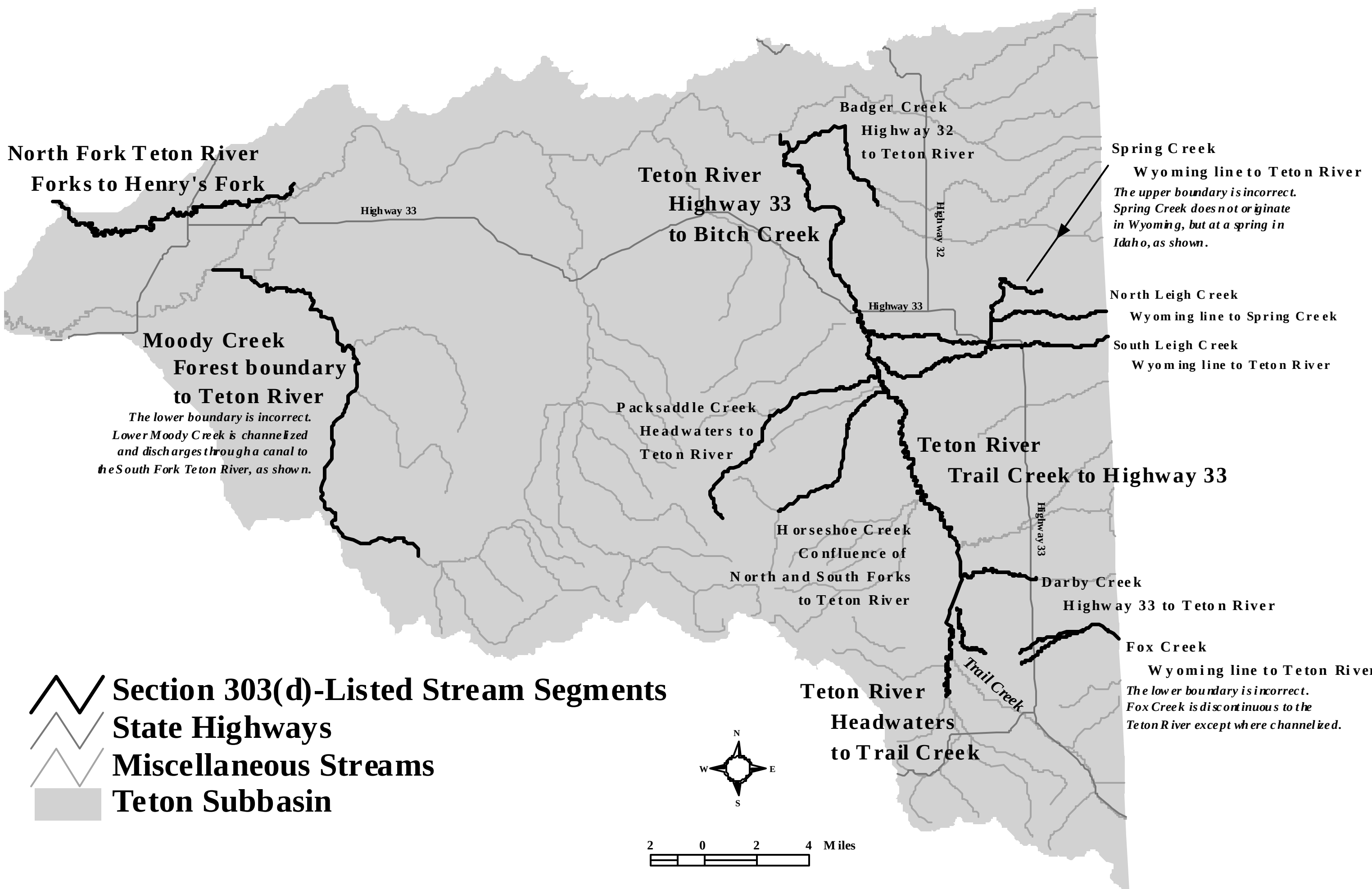

Figure 13. Section 303(d)-listed stream segments in the Teton subbasin. Segment boundaries and explanations of boundaries are shown below the stream names.

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Pollutant Targets

Because Idaho's water quality criteria for sediment and nutrients are narrative, as opposed to numeric, recognizing that violations of these criteria have occurred is a two-step process. First, it must be determined that a beneficial use has been impaired, and second, a cause-and-effect relationship between the pollutant and impairment of the beneficial use must be established. In contrast, temperature criteria are numeric, so recognizing a criterion violation is relatively simple when temperature data are available.

One objective of this assessment is to determine whether the pollutants identified on the §303(d)-list are in fact responsible for impaired water quality so that a TMDL for the pollutants can be established. This can most easily be accomplished by comparing data for sediment and nutrients to a numeric value that is generally considered to be protective of beneficial uses. In the absence of state numeric criteria, Idaho DEQ has proposed numeric *targets* for use in TMDL development (Table 15). Targets for sediment were recommended by Rowe *et al.* (1999) based on a review of published scientific literature, technical reports, and water quality criteria adopted by Montana, Wyoming, Utah, Nevada, Oregon,

Washington, and British Columbia. The sediment targets listed in Table 15 are just a few of the possible targets recommended by Rowe *et al.* (1999), and were selected for this assessment because they are consistent with available data. The targets listed for nutrients are also based on a review of the scientific literature, and are intended to prevent "biological nuisance" or "excessive plant growth in streams" (Essig 1998).

To provide a context for the significance of these targets, the biological effects of sediment and nutrients are discussed below, along with explanations of various methods for analyzing these pollutants.

Sediment

Sediment is the most common stream pollutant nationwide, both in terms of the quantity delivered on an annual basis and the number of stream miles affected (Waters 1995). In relatively undisturbed watersheds, streams constantly assimilate sediment delivered through natural geological processes. Sediment is considered a pollutant only when it is produced at accelerated rates and in excessive amounts by human activities. Activities that commonly accelerate sediment production are row cropping, livestock grazing in riparian areas, timber harvest, mining, road construction, residential and industrial development, stream channelization, and stream bed alteration (Waters 1995). All of these activities currently occur or have occurred in the Teton Subbasin.

Table 14. Water quality criteria pertaining to pollutants shown in Idaho's 1998 §303(d) list of water quality limited waterbodies.

Pollutant	Water Quality Criteria Excerpted From IDAPA 58.01.02
Sediment	200. GENERAL SURFACE WATER QUALITY CRITERIA. 08. Sediment. Sediment shall not exceed quantities specified in Sections 250 or 252, or, in the absence of specific sediment criteria, quantities which impair designated beneficial uses. Determinations of impairment shall be based on water quality monitoring and surveillance and the information utilized as described in Subsection 350.
Flow Alteration	None
Nutrients	200. GENERAL SURFACE WATER QUALITY CRITERIA. 06. Excess Nutrients. Surface waters of the state shall be free from excess nutrients that can cause visible slime growths or other nuisance aquatic growths impairing designated beneficial uses.
Habitat Modification	None
Thermal Modification (Temperature)	250. SURFACE WATER QUALITY CRITERIA FOR USE CLASSIFICATIONS. 02. Cold Water. Waters designated for cold water aquatic life are to exhibit the following characteristics: b. Water temperatures of twenty-two (22) degrees C or less with a maximum daily average of no greater than nineteen (19) degrees C. e. Salmonid spawning: ii. Water temperatures of thirteen (13) degrees C or less with a maximum daily average no greater than nine (9) degrees C. 03. Seasonal Cold Water. Between the summer solstice and autumn equinox, waters designated for seasonal cold water aquatic life are to exhibit the following characteristics. For the period from autumn equinox to summer solstice the cold water criteria will apply. b. Water temperatures of twenty-seven (27) degrees C or less as a daily maximum with a daily average of no greater than twenty-four (24) degrees C.

Table 15. Water quality targets for sediment (Rowe *et al.* 1999) and nutrients (Essig 1998).

Pollutant	Target
Sediment	Turbidity Not greater than 50 NTU[1] instantaneous or 25 NTU for more than 10 consecutive days above baseline background, per existing Idaho water quality standard; chronic levels not to exceed 10 NTU at summer base flow Total suspended solids Not to exceed 80 milligrams per liter (mg/L), regardless of season Subsurface sediment For those streams with subsurface fine sediment (i.e., particles less than 6.3 mm in diameter) less than 27%, do not exceed the existing fine sediment volume level; for streams that exceed the 27% threshold, reduce subsurface sediment to a 5-year mean not to exceed 27% with no individual year to exceed 29%; concentration of subsurface sediment <0.85 mm should not exceed 10%
Nutrients	Total phosphorus Less than 0.1 mg/L in flowing streams to prevent biological nuisance Total nitrate as N Less than 0.3 mg/L Total nitrogen as N Less than 0.6 mg/L

[1]Nephelometric turbidity unit

Sediment Terminology Sediment is defined as "particulate matter that has been transported by wind, water or ice and subsequently deposited" (Lincoln *et al.* 1993). Consequently, sediment is sometimes used to refer to stream channel substrate materials that range in size from microscopic particles to boulders. But as a nonpoint source pollutant, sediment typically refers to small soil and rock particles mobilized and transported to streams by runoff from land surfaces or by erosive forces acting on exposed streambanks. Larger particles such as cobbles and boulders are not considered pollutants because they are generally beneficial to stream organisms (Waters 1995).

Instream sediment is classified according to the manner in which it is transported. Sediment particles transported in the water column are referred to as suspended sediment; particles transported along the bed or very close to the bed are referred to as bed load. The USGS specifically defines bed load as particles that roll, slide, or skip along the stream bed or within 0.25 feet of the stream bed (Brennan *et al.* 2000). The sizes of particles that are transported in suspension or as bed load depend on factors such as the gradient of the stream bed and water velocity. According to Waters (1995), suspended sediment is usually comprised of particles less than 62 micrometers (µm) (0.062 mm) in size. MacDonald *et al.* (1991) describe particles smaller than 62 µm as wash load, which they define as particles that are washed into streams during runoff events, are smaller than stream bed materials, and remain suspended in the water column the entire length of the fluvial system. These authors also acknowledge that the concept of wash load is rarely used by fluvial geomorphologists and fisheries biologists. Citing other authors, they conclude that for streams in the Pacific Northwest, particles less than 100 µm (0.1 mm) in diameter are typically transported as suspended sediment; particles between 0.1 and 1 mm in diameter are typically transported as bedload, but can be transported as suspended load during turbulent, high flow events; and particles larger than 1 mm are typically transported as bedload (Everest *et al.* 1987 and Sullivan *et al.* 1987, as cited in MacDonald *et al.* 1991).

Although the smallest sediment particles generally remain suspended in the water column of a stream, some suspended sediment is deposited and becomes part of the stream channel substrate. A variety of classification systems have been proposed to standardize terminology used to describe substrate sediment, but none has been universally adopted by stream ecologists and fisheries biologists to describe substrate sediment. Most classification systems are based on the Udden grade scale and Wentworth naming convention, and associate ranges of particle sizes with descriptive terms such as clay, silt, sand, gravel, cobble, and boulder (Table 16). The Udden scale uses 1 mm as a fixed reference, and all size categories smaller or larger are determined by sequential halving or doubling of the 1-mm reference. In a paper describing techniques for studying benthic invertebrates, Cummins (1962, as cited in Waters 1995) described a substrate classification system consisting of eleven categories based on the Wentworth scale. The EPA protocol for in-stream rapid bioassessment includes a substrate classification system that appears to be based on Cummins' system but contains only seven size categories (Plafkin *et al.*1989). Platts *et al.* (1983) classified substrate materials into six categories, and assigned the descriptive terms, "fine sediment - large" to particles 0.83 to

4.71 mm in size and "fine sediment - fine" to particles less than 0.83 mm in size. But Platts *et al.* (1983) also recommended that specialists working with stream channel substrates adopt a classification system based on terminology of the American Geophysical Union, which is similar to that used in the Udden and Wentworth scales. Researchers studying the effects of sediment on egg incubation and fry emergence have often classified substrate materials using a series of sieves of successively smaller mesh size. This provides a relatively rapid and reproducible method of quantifying substrate particle sizes without performing tedious or elaborate particle size measurements. For example, McNeil and Ahnell (1964) used Tyler sieves with mesh openings of 26.26 mm, 13.33 mm, 6.68 mm, 3.33mm, 1.65 mm, 0.833 mm, 0.417 mm, 0.208 mm, and 0.104 mm to study the relationship between sizes of spawning bed materials and salmon spawning success. The mesh sizes given in mm correspond to the following mesh sizes in inches: 1.03 inch, 0.52 inch, 0.26 inch, 0.13 inch, 0.06 inch, 0.03 inch, 0.016 inch, 0.008 inch, and 0.004 inch. They implicitly defined materials passing through a 0.833-mm mesh as "silts and fine sands" and "fine particles," and demonstrated the relationship between these materials and the permeability of spawning beds.

Table 16. **Classification of stream substrate materials by particle size (Lane 1947, as cited in Platts *et al*. 1983).**

Category	Size Range (mm)	Size Range (inches)
Very large boulders	4,096 - 2,048	160 - 80
Large boulders	2,048 -1,024	80 - 40
Medium boulders	1,024 - 512	40 - 20
Small boulders	512 - 256	20 - 10
Large cobbles	256 - 128	10 - 5
Small cobbles	128 - 64	5 - 2.5
Very coarse gravel	64 - 32	2.5 - 1.3
Coarse gravel	32 - 16	1.3 - 0.6
Medium gravel	16 - 8	0.6 - 0.3
Fine gravel	8 - 4	0.3 - 0.16
Very fine gravel	4 - 2	0.16 - 0.08
Very coarse gravel	2 - 1	0.08-0.04
Coarse sand	1.0 - 0.5	0.04-0.02
Medium sand	0.50 - 0.25	0.02-0.01
Fine sand	0.250 - 0.125	0.010 -0.005
Very fine sand	0.125 - 0.062	0.0050 - 0.0025
Coarse silt	0.062 - 0.031	--
Medium silt	0.031 - 0.016	--
Fine silt	0.016 - 0.008	--
Very fine silt	0.008 - 0.004	--
Coarse clay	0.002 - 0.004	--
Medium clay	0.001 - 0.002	--
Fine clay	0.0005 - 0.0010	--
Very fine clay	0.0005 - 0.00024	--

Bjornn *et al.* (1974 and 1977, as cited in Waters 1995) showed that the availability of physical habitat for juvenile salmonids in streams with granitic substrates was reduced when cobble-sized substrate was embedded by sediment, which the authors defined as substrate less than 6.35 mm in diameter. Tappel and Bjornn (1983) classified fines into two size categories, less than 9.5 mm and less than 0.85 mm, and developed a model using those substrate sizes to predict survival to emergence of five trout species. In a review of the effects of fine sediment in salmonid redds, Chapman (1988) concluded that most researchers use the terms “fine sediment” or “fines” to indicate particles smaller than about 6 mm in diameter. As these studies illustrate, the terms “sediment” and “fine sediment” have been assigned to a large range of particle sizes by researchers attempting to demonstrate a relationship between a defined particle size class and impaired spawning. Many of the size thresholds identified in these studies correspond to the mesh openings in U.S. Standard Sieves (Table 17).

According to Bjornn *et al.* (1998), research regarding salmonid reproductive success has focused on the effects of sediment particles as large as 9.5 mm because of an interest in evaluating the effects of logging and road-building in the Idaho Batholith, an area characterized by granitic soils and relatively large sediment particles. They noted that "[t]he effects of silt and clay-sized particles, that erode from sedimentary and metamorphic deposits, ...has not been studied extensively." They conducted a laboratory study of the effects of sediment less than 0.25 mm (250 µm) on the incubation and emergence of salmonid embryos, and concluded that:

> There may not be a single measure of fine sediments that can be used universally to predict survival or assess quality of stream beds used for spawning. ...we provided evidence that embryo survival can vary depending on the size and amount of fine sediments in the egg pocket; 6-7% of the <0.25 mm fines reduced survival from 80% to 20%, whereas with fine granitic sediments (<6.35 mm with few fines smaller than 0.25 mm), fines had to make up more than 20% of the substrate to reduce survival (Irving and Bjornn 1984).

This conclusion is particularly relevant to the type of sediment deposited in the streams of the Teton Subbasin where soils originate from volcanic and sedimentary materials, not granitic materials. The predominant soils in the Teton Subbasin are loams consisting of clay, silt, and sand, and in some locations, gravels.

The Biological Effects of Sediment in Streams Studies of the biological effects of sediment in North American streams were recently reviewed and summarized by Waters (1995) and Rowe *et al*. (1999). Populations of aquatic organisms have developed a variety of strategies for coping with intermittent increases in the concentrations of suspended sediment and bedload sediment, otherwise they would not persist in streams subjected to seasonal fluctuations in sediment load. But when streams are subjected to excessive sediment loads, aquatic organisms and communities of organisms may be affected in a variety of ways (Table 18).

According to Waters (1995), "[t]he influence of sediment deposition on the productivity of benthic organisms as food for fish is one of the most critical problems affecting stream fisheries." The abundance of benthic invertebrates is highest in stream substrates that consist of a heterogeneous mixture of gravel, pebbles, and cobbles; abundance is lowest in homogeneous substrates consisting of sand, silt, or large boulders and bedrock. Deposition of sediment can reduce the heterogeneity of substrate by filling the interstitial or open spaces around substrate particles.

Table 17. Categories of stream substrate materials and corresponding sieve by particle size.

Classification Based on Sediment Terminology of the American Geophysical Union (Lane 1947, as cited in Platts *et al.* 1983)		Corresponding Tyler Screen or U.S. Standard Sieve Number			
		Tyler Screens		U.S. Standard	
Category	Size Range (mm)	Mesh	Size of Opening (mm)	No.	Size of Opening (mm)
Fine gravel	8 - 4	8	2.36	--[1]	--
Very fine gravel	4 - 2	9	2.00	10	2.00
Very coarse gravel	2 - 1	16	1.00	18	1.00
Coarse sand	1.0 - 0.5	32	0.500	35	0.500
Medium sand	0.50 - 0.25	60	0.250	60	0.250
Fine sand	0.250 - 0.125	115	0.125	120	0.125
Very fine sand	0.125 - 0.062	250	0.063	230	0.063
Coarse silt	0.062 - 0.031	<400	0.038	--	--

[1]No corresponding U.S. Standard Sieve

Embeddedness, defined by Waters (1995) as "the fraction of substrate surfaces fixed into surrounding sediment," reduces the amount of habitat available to larval insects of the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Collectively, these insects are referred to as "EPT," and are the primary food for foraging fish. As embeddedness increases, the percentage of the benthic insect community composed of EPT declines, and the percentage of burrowing insects such as *Hexagenia* (burrowing mayfly), chironomids (midges), and oligochaetes (worms) increases (Waters 1995). Because these burrowing insects are not available to fish, the food base for fish is diminished. Furthermore, the occurrence in Rocky Mountain streams of *Tubifex tubifex*, the worm host of the parasite that causes whirling disease, is strongly predicted by low percentages of EPT in the insect community (Gustafson 1998).

Waters (1995) and MacDonald *et al.* (1991) reviewed the effects of suspended sediment on stream organisms, on the physical characteristics of water and channel morphology, and on beneficial uses such as drinking water supply. Because suspended sediment reduces light penetration through the water column, photosynthesis by aquatic plants is diminished and primary production is reduced. Invertebrate drift (i.e., downstream movement of invertebrates following detachment from the substrate) increases, possibly because of reduced food availability. According to Waters (1995), a major sublethal effect of high suspended solids is the loss of visual capability in fish, leading to reduced feeding and depressed growth. The ability of juvenile coho salmon to capture prey has been shown to be reduced by concentrations of 300 to 400 milligrams per liter (mg/L) suspended sediment (Noggle 1978 as cited in MacDonald *et al.*1991).

Table 18. The biological effects of excess sediment in streams (adapted from Waters 1995).

Primary Producers

- Photosynthesis is reduced by suspended sediment which increases turbidity and reduces light penetration through the water column. Sustained, reduced photosynthesis and primary production would probably reduce production of invertebrates and fish, but these effects have not been documented.

Invertebrates

- Drift (i.e., downstream movement of invertebrates in the water column) increases, presumably because suspended sediment decreases light penetration through the water column. Prolonged periods of high suspended sediment may deplete benthic invertebrate populations.

- Insect habitat is reduced by increasing embeddedness (i.e., “the fraction of substrate surfaces fixed into surrounding sediment”). Habitat reduction reduces the total numbers of insects belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera. These insects, known collectively as EPT, occupy the interstitial spaces within the stream bed and are a primary food for foraging fish.

- Insect habitat changes from heterogeneously sized substrate to homogeneously sized fine sediments. Available habitat for EPT declines, reducing food available to fish, and habitat for burrowing insect larvae such as chironomids and oligochaetes increases.

Fish

- Salmonids avoid turbid water and water containing high concentrations of suspended sediment. Concentrations of suspended sediment that trigger avoidance behavior probably vary among species and life stages. Avoidance may cause stream segments or entire streams to be devoid of fish.

- Salmonids exposed to varying concentrations of suspended sediment may experience a variety of sublethal effects including depressed growth rate due to inability of fish to see and capture prey, gill-flaring and reduced respiration, reduced tolerance to disease and toxicants, physiological stress, and altered behavior.

- Developing fish embryos and sac fry suffocate when the movement of water and oxygen into the interstitial spaces of redd gravels is impeded. This occurs most commonly in high-elevation streams in which downwelling water forces sediment into the interstitial spaces between gravels, preventing movement of oxygenated water around the embryos.

- Emergence of fry from the redd is prevented by impenetrable, densely consolidated substrate materials. Although embryo development and hatching are successful, reproductive failure occurs because fry cannot move from the redd to the water column.

- Winter survival of fry is diminished by the loss of protective interstitial spaces in riffles. “Severe reductions in year-class strength occur when a cohort of salmonid fry faces stream riffles heavily embedded by sediment deposits.”

- Growth of juveniles is reduced because rearing habitat in pools is lost. “When heavy deposits [of sediment] eliminate pool habitat, reduced growth and loss of populations result.”

Salmonids are generally known to prefer clear stream waters, and studies have demonstrated that several species actively avoid waters containing high concentrations of suspended sediment. Other sublethal effects such as gill damage, respiratory distress, reduced tolerance to disease and toxicants, and physiological stress have also been documented. Suspended sediment may indirectly affect aquatic organisms by increasing heat absorption and raising water temperatures, though this effect may be offset by higher reflectance and reduced heat absorption by substrate materials (MacDonald *et al.* 1991). Although effects on stream channel morphology are considered minor, some studies have shown that increased concentrations of suspended sediment cause increased water velocity and steeper channel gradient. The suitability of surface water as a drinking water source may be impaired by suspended sediment for aesthetic reasons and because high concentrations reduce the efficacy of water treatment. The suitability of water as an agricultural and industrial supply may also be impaired because of the damage suspended sediment may cause to irrigation pipes and sprinklers and hydroelectric turbines.

Measurement of Sediment As previously stated, Idaho's water quality standards do not contain numeric criteria for suspended sediment or total suspended solids (TSS), but criteria have been established for turbidity. Turbidity is an optical property of water and a measure of the light scattered and absorbed by suspended sediment, colored organic compounds, and microscopic organisms (APHA 1992). Although a relationship exists between suspended sediment and turbidity, establishing a direct correlation between the two measurements is difficult because turbidity is affected by the sizes, shapes, and refractive indices of the materials in suspension. Nevertheless, turbidity is frequently used as a surrogate measure of suspended solids because of the relative ease with which it can be measured. Although the effect of turbidity on the beneficial use of cold water aquatic life is not well characterized, turbidity is known to reduce the effectiveness of water disinfection, thereby interfering with the beneficial use of surface water as a drinking water supply.

Turbidity measurements were originally based on the Jackson candle turbidimeter, and analytical results were expressed in Jackson turbidity units (JTUs). Because of poor sensitivity at low turbidities, this method was replaced in the 1980s by the nephelometric method that gives results in nephelometric turbidity units (NTUs) (APHA 1992). Turbidity is also sometimes reported as formazin turbidity units (FTUs) (Salvato 1992) because formazin is used as a standard for calibration. There is no direct relationship between NTU or FTU readings and JTU readings, so data collected using these methods cannot be directly compared (Salvato 1992).

The numeric criteria for turbidity, as specified in *IDAPA 58.01.21 - Water Quality Standards and Wastewater Treatment Requirements*, pertain to streams designated for cold water aquatic life and domestic drinking water uses. But because none of the streams in the Teton Subbasin have been designated as domestic water supplies, the only turbidity criterion that pertains to the subbasin is as follows:

> For cold water aquatic life use designations (*IDAPA 58.01.21.250.02.d*):
> Turbidity, below any applicable mixing zone set by the Department, shall not exceed background turbidity by more than fifty (50) NTU for more than ten (10) consecutive days.

Title 40, Part 136 of the Code of Federal Regulations lists inorganic test procedures approved for analysis of pollutants. Neither sediment nor suspended sediment is specifically listed as a parameter for which a method has been approved, so the method commonly used by laboratories is EPA method 160.2 for analysis of nonfilterable residue (EPA 1983) or *Standard Methods* 2450 D for analysis of TSS (APHA 1992). Another method used by some laboratories is the American Society for Testing and Materials designation D3977-80, "Standard practice for determining suspended-sediment concentration in water samples." According to these procedures, water is filtered through a glass microfiber filter that retains particles larger than approximately 1.5 mm in diameter (Pharoah 2000). The filter is dried at approximately 105 ^{o}C and weighed to obtain the mass of sediment, in milligrams, per volume of water sampled, in liters. Because of the relatively low drying temperature, the weight of the material on the filter includes organic, as well as inorganic material. The primary difference between the procedures is in regard to the volume of sample or subsample filtered.

An accurate and reliable method for measuring suspended sediment, particularly for the purpose of TMDL development, is currently being investigated by the USGS (Gordon and Newland, undated). The USGS has determined that significant differences in analytical results can occur using the methods cited above because of differences in the volume of sample analyzed and procedures for subsampling. Some of these procedures were originally developed for evaluating the efficacy of wastewater treatment, not for analysis of natural stream waters. Another factor that must be considered when analyzing for TSS or suspended sediment is the procedure used to collect the sample in the field. The USGS specifies that water intended for analysis of suspended sediment should be collected with a depth-integrating sampler at several vertical locations in the stream cross section (Brennan *et al.* 2000).

Subsurface sediment is measured by removing a portion of the stream bed substrate, separating substrate particles into various size classes, then determining the percentage of particles within each size class. Herron (1999) measured substrate sediment in streams in the Salmon River basin using a modification of the procedure described by McNeil and Ahnell (1964). He then used the results as the basis for some of the first sediment TMDLs developed in Idaho. Subsurface fine sediment was defined as less than 6.35 mm (0.25 inches), and targets of less than 28% subsurface fine sediment to a depth of 4 inches were specified in the TMDLs (DEQ 1999c). The procedure used to measure subsurface fine sediment is described in Appendix G.

The BURP protocol defines fine sediment as particles less than 6 mm in size. As part of the habitat assessment protocol conducted at sites selected for BURP sampling, the percentage of fine sediment in the stream bed is determined using a modified version of the Wolman pebble count. This procedure was originally developed to assess the hydrologic features of streams, and has been widely recommended as an efficient and reproducible means of evaluating the suitability of stream substrates for aquatic life (Mebane 2000). The BURP protocol specifies measurement of a minimum of 50 surface particles encountered at equidistant intervals across the width of the stream at three riffle locations (DEQ 1996a). Initially, pebble counts were made across the bankfull width of the stream, but beginning in 1997 pebble counts were made across the wetted width of the stream only. Counts of pebbles across the entire bankfull transect include counts of particles in the streambanks that are only submerged by water at high flows.

This procedure skews the count toward a high percentage of fine sediment because streambanks are usually composed of finer particles than the stream bed. An analysis of data from more than 200 BURP locations across Idaho showed that percentages of fine sediment measured across the bankfull width of streams averaged 45%, whereas percentages of fine sediment measured across the wetted width of the stream averaged only 25% (Mebane 2000). But regardless of whether pebble counts were conducted for bankfull or wetted stream width, the data showed a statistically significant inverse correlation between the percentage of surface fine sediment and the richness of EPT species (Mebane 2000).

Embeddedness is another parameter monitored during the habitat evaluation phase of BURP sampling. Embeddedness is defined by Hayslip (1993) as the degree to which boulders, rubble, or gravel in riffles are surrounded by fine sediment less than 6.35 mm (0.25 inch) in diameter. The size threshold for fine sediment specified by Hayslip (1993) is slightly larger than the size threshold specified by the modified Wolman pebble count (6 mm), and is another example of the variety of ways in which fine sediment is defined. Embeddedness is a qualitative measure of fish and macroinvertebrate habitat quality, with 0-25% embeddedness considered optimal, 25-50% embeddedness considered sub-optimal, 50-75% embeddedness considered marginal, and more than 75% embeddedness considered poor. Each BURP site receives an embeddedness score between 0 and 20, which is combined with ten other habitat parameter scores to obtain a habitat index (HI) score.

Nutrients

Excessive concentrations of nutrients, specifically nitrogen and phosphorus, may diminish water quality and impair beneficial uses through the process of eutrophication. Very simply, eutrophication occurs when excess nutrients stimulate the growth of primary producers such as algae and aquatic macrophytes. The plant biomass produced is greater than the amount that can be utilized by consumers such as invertebrates and fish. The accumulated biomass decomposes, and dissolved oxygen is consumed more quickly than it can be replenished by other processes. The process of eutrophication has been well documented in lakes and reservoirs, but is less well understood in the flowing waters of streams and rivers.

The Biological Effects of Nutrients Depletion of dissolved oxygen is just one of many chemical and biological effects that may occur when excessive nutrient concentrations disrupt the equilibrium between energy production and utilization. These effects can limit the capacity of a surface water to support its beneficial uses, as described in Table 19. Idaho’s water quality standards address these effects through narrative and numeric criteria. Narrative criteria address floating, suspended, or submerged matter; excess nutrients; and oxygen-demanding materials. Numeric criteria address dissolved oxygen, ammonia, and turbidity (Table 19). Numeric criteria specific for nitrogen and phosphorus have not been developed because concentrations that are excessive can only be defined within the context of the physical, chemical, and biological attributes of the aquatic system affected.

The macronutrients nitrogen (N) and phosphorus (P) are essential for plant growth; if they are not available in adequate amounts and in the necessary proportions, plant growth is limited. The chemical forms of nitrogen and phosphorus that are most readily utilized by plants are dissolved ammonium (NH_4^+), dissolved nitrate (NO_3-), and dissolved orthophosphorus (PO_4^{-3}). Fresh water algae and macrophytes typically contain nitrogen and phosphorus in a ratio of seven parts nitrogen to one part phosphorus (7 N:1 P), but average river water contains a ratio of 23 parts nitrogen to less than one part phosphorus (23 N:<1 P) (Wetzel 1983). Mitsch and Gosselink (1993) cite data indicating that the "average" concentration of nitrogen in rivers world-wide is 0.2 mg/L and the "average" concentration of phosphorus is 0.02 mg/L. These concentrations are comparable to a ratio of 10 N: 1P which is much lower than that cited by Wetzel (1983). Because phosphorus is much less abundant than nitrogen in fresh water, phosphorus is the growth-limiting nutrient in most inland lakes and rivers. Thomas *et al.* (1999) cited studies which indicate that growth of aquatic algae is phosphorus limited in waters in which the ratio exceeds 20 N:1 P, but is nitrogen limited in waters in which the ratio is less than 10 N:1 P.

Very few researchers have attempted to define the concentrations of nitrogen and phosphorus that stimulate aquatic plant production in fresh waters. Rupert (1996) states that 0.3 mg/L $NO_2 + NO_3$ as N is the "critical limit" for growth stimulation in the presence of adequate phosphorus, and 0.05 mg/L orthophosphorus is the "critical limit" in the presence of adequate nitrogen. Other researchers have recommended 0.3 mg/L NO_3 or 0.6 mg/L total nitrogen as targets not to be exceeded in fresh water streams and rivers, but there does not appear to be a consensus in the literature that this concentration is the absolute maximum that can occur in all fresh waters without causing nuisance plant growth (Essig 1998). The EPA has not promulgated a criterion for total phosphorus, but it has published information that may support development of such a criterion (EPA 1986). To prevent development of biological nuisance and to control accelerated or cultural eutrophication, the EPA "Gold Book" states that "total phosphates as phosphorus (P) should not exceed 50 ìg/L (0.05 mg/L) in any stream at the point where it enters any lake or reservoir, nor 25 ìg/L (0.025 mg/L) within the lake or reservoir." But for flowing waters not discharging directly to lakes or impoundments, the "Gold Book" cites Mackenthun (1973) in recommending 100 ìg/L (0.1 mg/L) total phosphorus as a desired goal for preventing plant nuisances.

Table 19. The primary and secondary effects of nutrient enrichment and the beneficial uses affected (after Geldreich 1996).

Primary Effects of Nutrient Enrichment	Secondary Effects of Nutrient Enrichment	Beneficial Uses Affected
Periodic growth of substantial populations of blue-green algae (*Anabaena flos-aquae*, *Microcystis aeruginosa*, *Oscillatoria* spp., and *Aphanizomen flos aquae*)	Toxins produced by blue-green algae may cause illness or death in mammals, birds, and fish, and skin irritation in humans.	Domestic water supply Agricultural water supply Aquatic life Primary contact recreation Secondary contact recreation
Development of mats of algae and increased growth of macrophytes	Increased growth of bacteria in water distribution systems due to nutrients released by decomposing algae; formation of methane, hydrogen sulfite and reductive compounds of iron and manganese, which may affect water treatment and distribution systems; depletion of dissolved oxygen due to plant decomposition; fish suffocation due to oxygen depletion; fish toxicity due increased concentrations of ammonia.	Domestic water supply Aquatic life
Increased production of phytoplankton, zooplankton, bacteria, and fungi	Organisms produce taste and odor compounds that reduce palatability; organisms resistant to disinfection may enter potable water supply; increased turbidity reduces effectiveness of water disinfection systems; decreased stability of communities and populations of aquatic organisms, including fish.	Domestic water supply Aquatic life

The only nitrate criterion established by the EPA is 10 mg/L for drinking water; there is no criterion for the protection of aquatic life. The EPA criteria to protect against eutrophication caused by phosphate phosphorus are as follows: 0.025 mg/L or less in lakes, 0.05 mg/L where streams enter lakes, and 0.1 mg/L in streams that do not flow into lakes (EPA 1986).

Measurement of Nutrients Nitrogen and phosphorus exist in several molecular forms. Some forms are water soluble while others are transported in water adsorbed to particles of soil or organic materials. Organic forms of nutrients contain carbon and hydrogen and are frequently derived from plant or animal tissue; inorganic nutrients are mineralized.

Nitrogen is often reported as total Kjeldahl nitrogen (TKN) or total nitrogen (TN). Total Kjeldahl nitrogen includes organic nitrogen and total ammonia. Total ammonia includes the un-ionized form (NH_3), which is toxic to fish, and ionized ammonia or ammonium (NH_4^+), which is not toxic to fish and is utilized as a nutrient by plants. Ionized ammonia is the prevalent form in natural waters, but the concentration of unionized ammonia increases rapidly with even small increases in pH and temperature. Total nitrogen includes TKN and nitrite plus nitrate (NO_2 + NO_3). Although NO_3 is the form available to plants, most water quality analyses are performed for NO_2 + NO_3. And because NO_2 is readily oxidized to NO_3 in surface waters, the concentration of NO_2 + NO_3 in surface water is generally assumed to consist primarily of NO_3. This assumption is made because of the time-consuming nature of NO_3 analyses. To obtain an accurate measurement of NO_3 in water, the sample must first be analyzed for NO_2, then for NO_2 + NO_3. The concentration of NO_2 is then subtracted from the concentration of NO_2 + NO_3 to give the concentration of NO_3. Even when NO_2 is present in detectable concentrations, it is a very small fraction of the total concentration of NO_2 + NO_3. Therefore, for the purpose of this assessment, it is appropriate to use the results NO_2 + NO_3 analyses as an approximation of NO_3 concentrations in surface waters.

The forms of phosphorus that are frequently reported for water are total phosphorus and orthophosphorus. Analysis of total phosphorus is performed on an unfiltered water sample and therefore includes dissolved phosphorus, dissolved orthophosphorus, phosphorus adsorbed to solids and soil particles, and phosphorus contained in organic material such as plant cells. When concentrations of suspended solids are low, total phosphorus may consist almost entirely of dissolved phosphorus. The concentrations of total phosphorus and dissolved phosphorus in a sample are usually much greater than the concentration of orthophosphorus, which is also referred to as orthophosphate or phosphate phosphorus.

SUMMARY AND ANALYSIS OF WATER QUALITY DATA

Beneficial Use Reconnaissance Program Data

Water quality can be monitored by measuring specific physical and chemical parameters or by assessing support of beneficial uses. Measurement of physical and chemical parameters is labor-intensive and relatively expensive, and the number of parameters that can be monitored as indicators of water quality is enormous. These constraints on water quality monitoring are just some of the factors that contributed to the development and implementation of the BURP by DEQ in the early 1990s. The purpose of BURP is to obtain data that reflect the cumulative effects of water quality on the biological component of the stream ecosystem, thereby providing a means of determining whether aquatic life beneficial uses are supported. If the beneficial use of cold water aquatic life is supported, DEQ assumes that other uses, which require less stringent water quality conditions (e.g., industrial and agricultural water supply), are also supported.

The BURP protocol focuses on benthic macroinvertebrate community sampling for the following reasons: 1) benthic macroinvertebrates are relatively immobile and therefore constantly subjected to the effects of water quality; 2) the structure of the macroinvertebrate community can indicate both the presence of detrimental water quality conditions such as excessive nutrients as well as the absence of beneficial water quality conditions such as organic carbon; 3) macroinvertebrates respond to the cumulative effects of water quality, including synergistic and antagonistic effects of pollutants; and 4) macroinvertebrate communities respond relatively quickly to changes in water quality. The numbers and types of macroinvertebrates found are used to calculate a macroinvertebrate biotic index (MBI) score. An MBI score greater than or equal to 3.5 indicates "full support" of cold water aquatic life; an MBI score less than or equal to 2.5 indicates "not full support" of cold water aquatic life; and an MBI score between 2.5 and 3.5 indicates that the support status "needs verification."

The support status of cold water aquatic life and salmonid spawning beneficial uses are influenced by physical factors such as water quantity and habitat structure, as well as water quality. Although DEQ has no authority relative to water quantity, it must determine 1) whether support of a beneficial use is impaired because of water quality or habitat conditions, and 2) the sources of pollutants that may be degrading water quality. Therefore, the BURP protocol also includes measurement of physical parameters such as cobble embeddedness, streambank stability, riparian vegetation, and woody debris in the area of the stream sampled for macroinvertebrates. These measurements are incorporated to produce a HI score, which is used to supplement the MBI score to assess support of the aquatic life beneficial use.

The support status of a waterbody assessed as “needs verification” on the basis of an MBI score can be verified using the HI score and/or the reconnaissance index of biotic integrity, a qualitative measure of a fish assemblage. Data to evaluate fish assemblages have been obtained from IDFG, the U.S. Forest Service, or BLM, and have been collected by DEQ using electrofishing techniques. If the HI score does not indicate habitat impairment or the fish assemblage is not impaired, the stream is reassessed as fully supporting the beneficial use of cold water aquatic life. Because the Teton Subbasin is located in two ecoregions, HI scores greater than 88 indicate non-impaired habitat conditions for streams located in the Snake River Basin/High Desert Ecoregion, and HI scores greater than 80 indicate non-impaired conditions for streams in the Middle Rockies Ecoregion (DEQ 1996b).

The support status of the beneficial use of salmonid spawning is also determined using fisheries data. Full support of salmonid spawning is indicated by the presence of three size classes of a single salmonid species, including young-of-year (i.e., fish less than 100 mm in length).

In 1997, DEQ completed the first cycle of waterbody assessments based primarily on BURP data. These data were collected from 1994 through 1996 on wadeable streams located in all subbasins of the state. The assessment process, which is described elsewhere (DEQ 1996a, 1998b), was used to determine whether a waterbody supported the beneficial uses of cold water aquatic life and salmonid spawning. This process was the basis for developing Idaho’s 1998 §303(d) list of water quality impaired waterbodies requiring TMDL development. The guidance for assessing the support status of beneficial uses has recently been revised (Grafe *et. al* 2002). Assessments of the beneficial uses of waterbodies sampled from 1997 through 2000 will now be performed.

Forty-two wadeable streams have been sampled at 71 sites in the Teton Subbasin using the BURP protocol (Figure 14). A preliminary analysis of this data was performed to determine whether the relationship between macroinvertebrates and surface sediment demonstrated by Mebane (2000) using BURP data collected statewide also could be shown for the Teton Subbasin. As previously discussed, Mebane (2000) found a statistically significant inverse correlation between the percentage of fine surface sediment and the richness of EPT species. Using BURP data for the Teton Subbasin shown in Appendix H, analyses were performed to determine whether MBI scores were correlated with percentages of fine sediment, and whether percentages of EPT were correlated with percentages of fine sediment. The percentages of surface fines were divided into four categories: less than 6 mm measured in the bankfull channel, less than 6mm measured in the wetted channel, less than 1 mm measured in the bankfull channel, and less than 1 mm measured in the wetted channel. Analyses were performed using VassarStats, a statistical program available on the Internet at http://faculty.vassar.edu/~lowry/corr_stats.html, and significance was indicated by a one-tailed p value of less than 0.05.

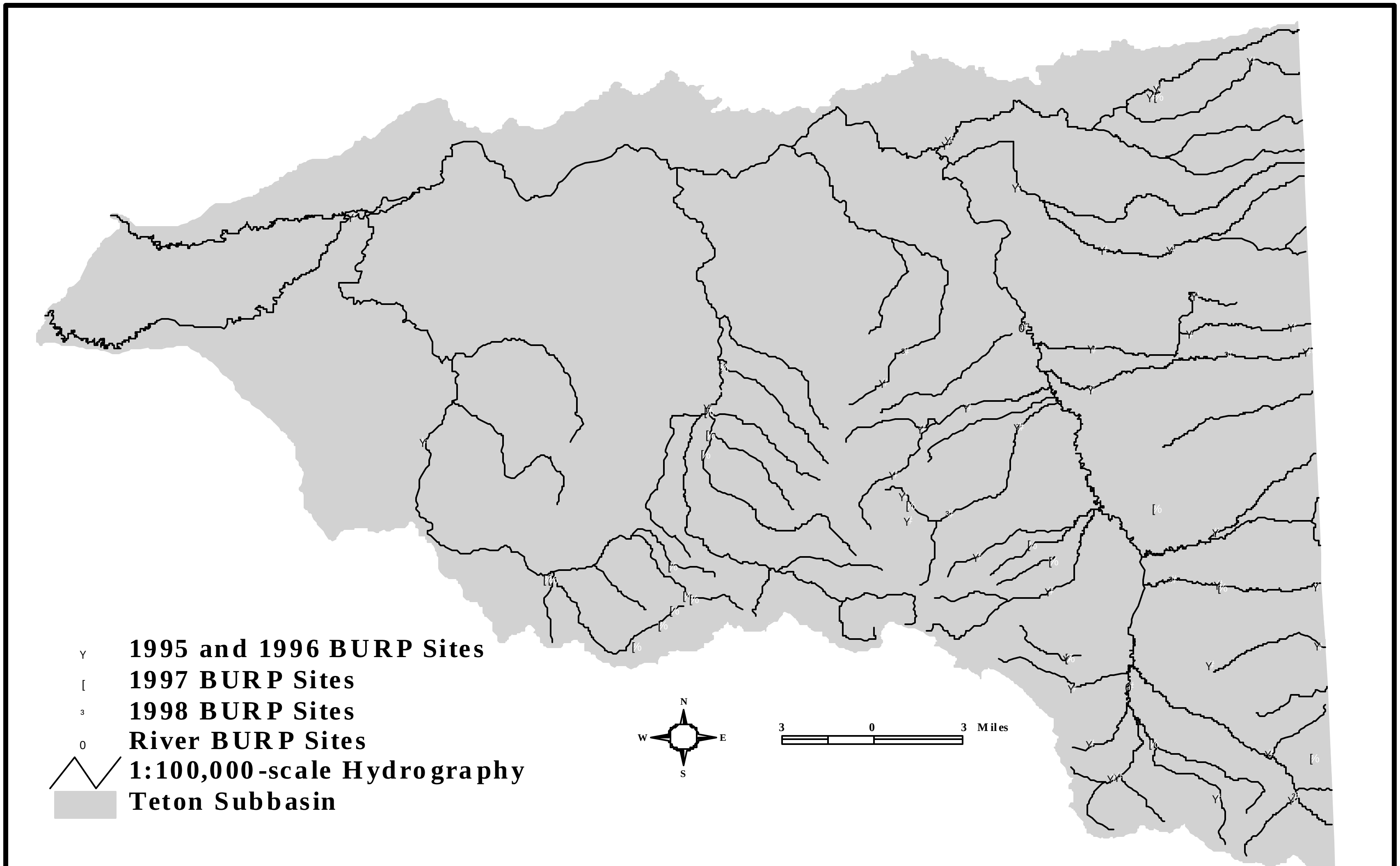

Figure 14. Beneficial use reconnaissance project (BURP) sampling sites.

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These analyses indicated that the percentage of fine sediment measured in the wetted width of the stream channel is a better predictor of desirable macroinvertebrate communities in the Teton Subbasin than the percentage of fine sediment measured in the bankfull width of the channel. Both MBI scores and percentages of EPT were negatively correlated with percentages of surface fines less than 6 mm and less than 1 mm when surface fines were measured in wetted channels, but statistically significant relationships were not observed between the same parameters when surface fines were measured in bankfull channels (Figures 15 and 16). Future measurements of surface fines in the Teton Subbasin, whether conducted as part of the BURP protocol or any other assessment procedure, should be performed in the wetted width of the stream channel.

Based on the relationship between surface fine sediment and MBI score or percentages of EPT, it appears that measurement of surface fine sediment may be a useful method for monitoring the effectiveness of implementation projects for restoring the beneficial use of cold water aquatic life in Teton Subbasin streams. It is important to note, however, that high MBI scores may occur at sites with very high percentages of surface sediment and low percentages of EPT may occur at sites with very low percentages of surface sediment. The correlations between surface fines and MBI score or percentage EPT was slightly stronger when using fines less than 1 mm than when using fines less than 6 mm (Figures 15 and 16), indicating that this size class is most detrimental to the invertebrate community.

Embeddedness does not appear to be as reliable as percentage of surface fine sediment for predicting the quality of the macroinvertebrate community, as represented by the MBI score or percentage of EPT. The correlation between MBI scores and embeddedness ratings was not statistically significant although the correlation between percentages of EPT and embeddedness was significant (Figure 17).

National Pollutant Discharge Elimination System Permit Program

Routine analysis of water quality is legally required under the National Pollutant Discharge Elimination System (NPDES) permit program for discharges of point source pollutants to surface waters. Only two NPDES permits have been issued in the Teton Subbasin in Idaho, and both are for municipal wastewater treatment facilities. These facilities are located in Rexburg (NPDES permit number ID0023817), which discharges effluent into the South Fork Teton River, and Driggs (NPDES permit number ID0020141), which discharges to Woods Creek, a wetlands complex about five miles from the Teton River. These facilities report the results of the following wastewater analyses to DEQ on a monthly basis: biological oxygen demand (BOD), pH, TSS, fecal coliform bacteria, flow, and total residual chlorine. It is important to note that these analyses are performed on the effluent discharged, not on the stream water receiving the effluent, and violations are determined according to the facility's specific NPDES permit requirements, not according to state water quality standards for surface waters. The results of these analyses are reported to EPA Region 10, which has primacy over the NPDES permit program, and to the Idaho Falls Regional Office of DEQ.

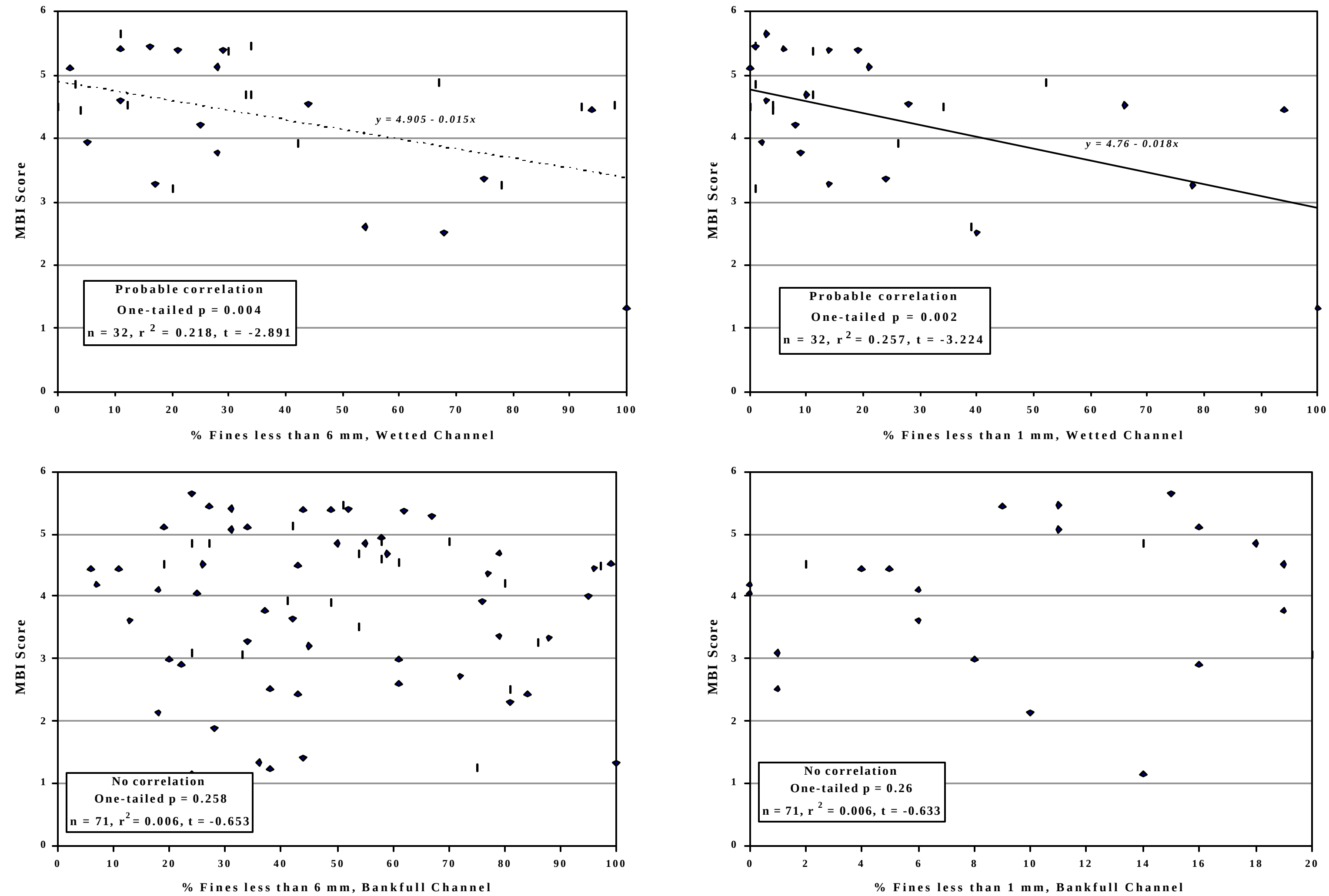

Figure 15. Macroinvertebrate biotic index (MBI) scores plotted against the percentages of fine substrate sediment less than 6 mm or 1 mm in size, as measured in wetted and bankfull channels. The MBI scores are negatively correlated with percentages of fine sediment measured in wetted channels, but are not correlated with percentages of fine sediment measured in bankfull channels.

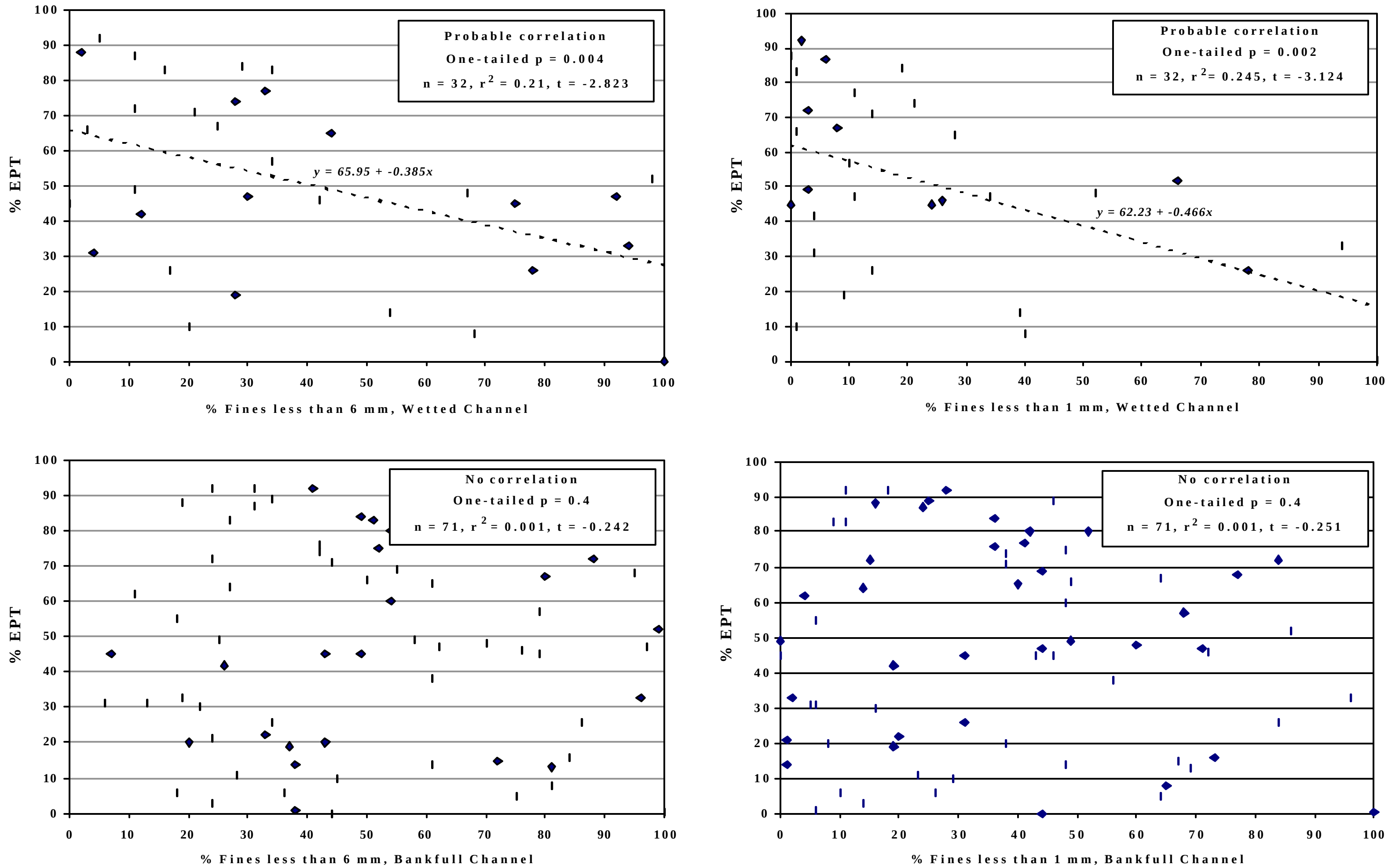

Figure 16. Percentages of insects belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) plotted against the percentages of fine substrate sediment less than 6 mm or 1 mm in size, as measured in wetted and bankfull channels. The percentages of EPT are negatively correlated with percentages of fine sediment measured in wetted channels, but are not correlated with percentages of fine sediment measured in bankfull channels.

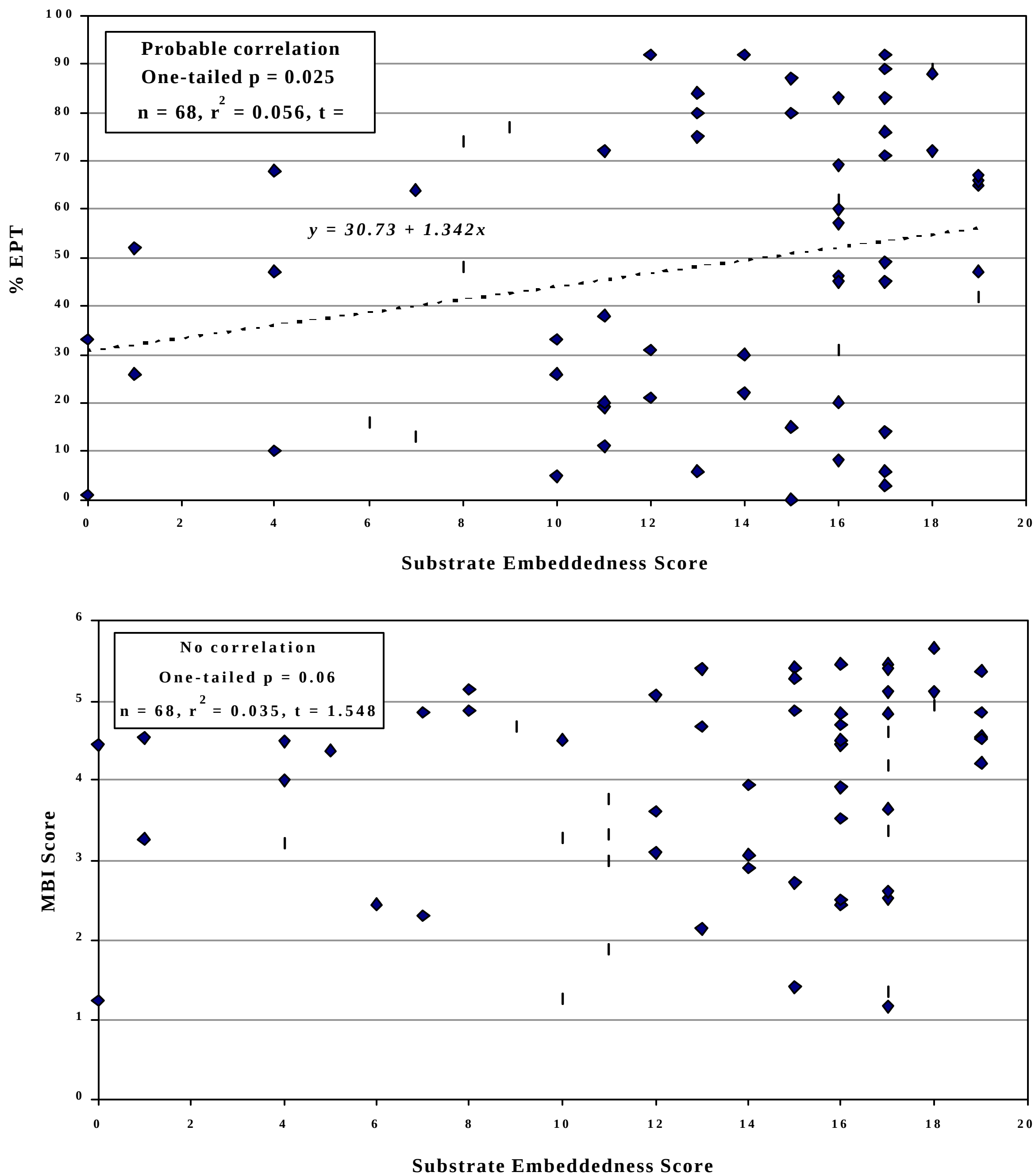

Figure 17. The relationships between percentages of insects belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) and embeddedness, and macroinvertebrate biotic index (MBI) scores and embeddedness. Embeddedness is scored qualitatively with 0 indicating the most-embedded substrate and 20 indicating the least-embedded substrate.

The wastewater treatment facility at Grand Targhee Ski and Summer Resort, located east of Driggs in Wyoming, went on line in 1998 and received NPDES permit number WY-24708 from the state of Wyoming, which has primacy for the program. The plant discharges about 20,000 gallons per day in winter and less than 8,000 gallons per day in summer to Dry Creek, a dry channel. The effluent discharged to Dry Creek infiltrates into the channel substrate before the Dry Creek channel converges with another stream (Woodward 2002). None of these wastewater discharges is expected to influence §303(d) listed waters in the subbasin.

In addition to analyses performed on its effluent, the Rexburg municipal wastewater treatment facility is also required to analyze water from the receiving stream (i.e., South Fork Teton River) for temperature, pH, and ammonia nitrogen. Samples for analyses are collected both upstream and downstream of the point of effluent discharge to determine the effect of the discharge on ambient water quality.

Because the Rexburg facility is considered a major discharger (i.e., discharges more than one million gallons of effluent per day), it is also required to perform whole effluent toxicity tests twice yearly. The results of tests conducted in May and November of 1998 and 1999 indicated that the effluent did not contain toxic chemicals in amounts or combinations sufficient to produce short-term chronic toxicity to the invertebrate cladoceran, *Ceriodaphnia dubia,* or the vertebrate fish, *Pimephales promelas* (fathead minnow). Again, it is important to note that the toxicity tests are performed using the effluent discharged by the facility, not the receiving water in the South Fork Teton River, to ensure that toxic chemicals in toxic amounts are not discharged to the river.

Water Column Data

Data for specific water quality parameters such as nitrate, suspended sediment, and temperature were sparse or nonexistent for most surface waters in the Teton Subbasin when this assessment began in 1999. Sources of data included 1) a habitat recovery study conducted from 1976 to 1980 on the North Fork Teton River (SCS 1982), 2) suspended sediment data measured from April 1977 through September 1978 by the USGS at the *North Fork Teton River at Teton, Idaho* gage, 3) water quality data measured intermittently from 1977 to 1996 by the USGS at the *Teton River near St. Anthony* gage, 4) water quality studies conducted by DEQ in the late 1980s (Drewes 1987, 1988, 1993), and 5) baseline nutrient and TSS data collected from 1995 through 1998 by the TSCD for a 15-year water quality improvement project on Bitch Creek. Additional reports (Clark 1994; TSCD 1990, TSCD 1991) and databases (EPA STORET, EPA BASINS model) were reviewed but were found to contain data that were originally reported in the sources cited above. During the course of this assessment, additional nutrient data became available from researchers at Idaho State University and the INEEL (Thomas *et al.* 1999, Manguba 1999, Minshall 2000), and temperature data became available from IDFG (Schrader 2000a) and the BOR (Bowser 1999).

In June and July 1999, DEQ measured turbidity at several stream locations throughout the subbasin, including §303(d)-listed streams. The frequency and distribution of sampling was insufficient to adequately characterize 'background turbidity,' but the analyses provided general information regarding turbidity values during a period of relatively high streamflow. Whenever possible, water samples were collected using a DH-48 depth-integrated sampler, though some samples were simply collected by submerging a sample bottle in the water column. Samples were analyzed using a Hach 2100P portable turbidimeter. The results of these analyses are discussed in the following section along with other data for sediment.

To supplement the limited amount of data available for §303(d)-listed stream segments, DEQ issued a contract in the summer of 2000 for water quality monitoring at 27 sites (Figure 18). Depending on flow conditions, sites were sampled in June, July, and August for TKN, nitrate nitrogen, TSS, stream temperature, pH, conductivity, turbidity, and discharge. Temperature data loggers were placed in streams listed for temperature (Fox Creek and Spring Creek), and subsurface fine sediment was measured in streams listed for sediment (Badger Creek, Darby Creek, Fox Creek, Packsaddle Creek, South Leigh Creek, and Spring Creek). Water depth prevented sampling of subsurface fine sediment in segments of the Teton River that were also listed for sediment. Sampling procedures and analytical methods are described by Blew (undated), and the results of water analyses are presented in Appendix I and discussed in subsequent sections of this report.

Sediment Data

Suspended sediment was measured at least once each month from March 1993 through September 1996 in the Teton River at the *Teton River near St. Anthony* gage. These results did not indicate that consistently high concentrations of sediment were being transported within the depth of the water column sampled. The average concentration of suspended sediment during this period was 8 mg/L while the maximum and minimum values were 38 mg/L and 1 mg/L, respectively (Appendix J). The greatest calculated mass of sediment discharged per day was 306 tons on May 25, 1993, which also corresponded to the highest measured flow of 3,650 cfs.

The results of TSS measured in 1995, 1996, 1997, and 1998 in Bitch Creek at the forest boundary and above its confluence with the Teton River indicated that the target concentration of 80 mg/L is occasionally exceeded during periods of relatively high discharge (Appendix K, Table K-3). Concentrations of 82, 85, and 90 mg/L TSS were measured at the mouth of Bitch Creek in May 1997, May 1996, and June 1995 when discharges were 300 cfs, 443 cfs, and 252 cfs, respectively. However, high discharge did not necessarily correspond to high TSS concentrations. For example, the highest discharge recorded (836 cfs), corresponded with a TSS concentration of 67 mg/L, and a discharge of 433 cfs corresponded with a TSS concentration of only 14 mg/L. Although TSS concentrations were generally higher at the mouth than at the forest boundary, this pattern was not always observed. In April 1997, TSS at the forest boundary was 35 mg/L and only 12 mg/L at the mouth. From mid-July through October, when discharges remained below 200 cfs, concentrations of TSS remained below approximately 10 mg/L. The results of TSS analyses in §303(d)-listed streams in June, July, and August 2000 were consistent with the results for Bitch Creek, with TSS concentrations ranging from less than detection to 27 mg/L (Appendix I).

The results of the limited turbidity data available for the Teton Subbasin indicate that most streams are unlikely to violate Idaho's turbidity criterion except during extreme runoff events or under conditions where sediment is actively resuspended in the water column. Ten turbidity samples collected at the USGS *Teton River near St. Anthony* gage from 1992 to

1996 ranged from only 0.3 to 6.4 NTU (Appendix J). The results of 35 turbidity analyses conducted by DEQ at 15 sites in June and July of 1999 ranged from 2 NTU to 34 NTU, with a median value of 9 NTU (Table 20). The turbidities measured in June, July, and August of 2000 by DEQ in §303(d)-listed streams ranged from 0.4 to 11 NTU (Appendix I). These values were well below the instantaneous target of 50 NTU above background.

The turbidity of water in Moody Creek in 1999 was exceptionally high when compared to all other sampling sites in the Teton Subbasin. Turbidity values at two sites in the natural stream channel were 57 NTU and 204 NTU. These sites were located near the lower end of the Moody Creek subwatershed, less than five miles upstream of the point at which Moody Creek is channelized. The turbidity of the stream water at the second site may have originated from the Enterprise Canal, which discharges to the stream approximately 500 meters upstream from the sampling site. Just below the second sampling site and approximately two miles east of the South Fork Teton River, the natural channel of Moody Creek has been straightened. The stream s flow is channeled directly to the South Fork or is diverted to the Woodmansee Johnson Canal. The turbidity of Moody Creek water below the point at which the stream is channelized was 70 NTU. This was a decrease of 130 NTU in a distance of approximately two stream miles. Materials causing turbidity were either settling out of the water column, or turbidity was diluted by inflows to Moody Creek from the Teton and East Teton Canals.

The relatively low values for total suspended sediment, TSS, and turbidity indicate that monitoring these parameters on a monthly or even weekly basis is unlikely to detect critical periods of sediment delivery and instream sediment transport. In 1985, 1986, and 1987, TSCD and Soil Conservation Service staff closely monitored runoff in the Milk Creek drainage and determined that high sediment loads were detected in streams for only a few hours following a major rain or runoff event (Smart 2000). If these parameters are incorporated into implementation monitoring plans, efforts should be made to sample at least twice each week during periods of runoff and, when possible, during heavy rain events.

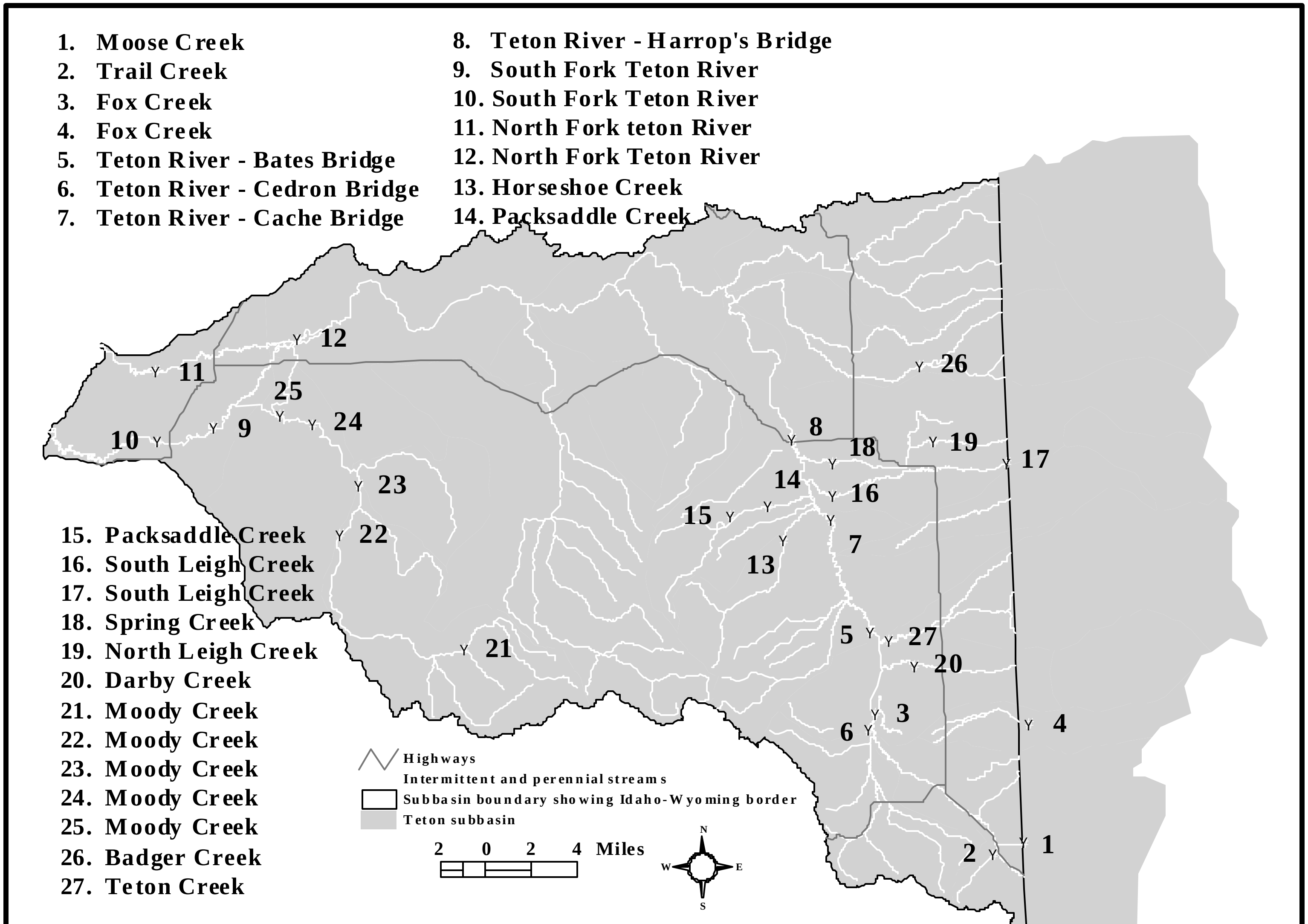

Figure 18. Approximate locations of DEQ water quality sampling sites in 2000.

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Table 20. Results of turbidity measurements performed in the Teton Subbasin in 1999.

Stream	Location	Date Sampled	Turbidity (NTU)[1]
Little Pine Creek	Blanchard Road (T3N R45E S19)	6-9-99	32
Warm Creek	South of Highway 31 on 1000S	6-9-99	17
Moose Creek	First bridge on Caribou-Targhee NF[2] (T42N R118W S32)	6-9-99	3
Fox Creek	Trail head on Caribou-Targhee NF (T42N R118W S5)	6-23-99	15
Fox Creek	~1 mile west of Caribou-Targhee NF boundary (T4N R46E S30)	6-23-99	21
Fox Creek	East of Highway 33 near 550S, 50W (T4N R45E S25)	6-9-99	2
Fox Creek	East of Highway 33 near 550S, 50W (T4N R45E S25)	6-23-99	26
Fox Creek	0.15 miles west of Highway 33 on 600S (R45E T4N S26)	6-23-99	22
Darby Creek	0.8 mile east of Caribou-Targhee NF boundary (R118W T43N S20)	6-23-99	4
Darby Creek	~2 miles west of Caribou-Targhee NF boundary (R45E T4N S13)	6-9-99	3
Spring Creek	Tributary of Teton Creek; Stateline Road (R46E T5N S32)	6-9-99	15
Spring Creek	Tributary of Teton Creek; Stateline Road (R46E T5N S32)	6-9-99	15
Spring Creek	Tributary of Teton Creek; west of Highway 33 and east of frontage road	6-9-99	34
Teton Creek	Stateline Road (R118W T44N S30)	6-9-99	3
Teton Creek	Stateline Road (R118W T44N S30)	6-23-99	5
Teton Creek	West side of Highway 33 at bicycle path (R45E T4N S2)	6-23-99	12
South Leigh Creek	East side of Highway 33 (R45E T6N S35)	7-1-99	3
South Leigh Creek	0.5 mile east, 0.5 mile north of Cache Bridge (R45E T5N S6)	7-1-99	4
North Leigh Creek	Below twin culverts on west side of 100E between 600N and 700N (R45E T6N S25)	7-1-99	7
Spring Creek	East of Tetonia on 650N (R45E T6N S27)	7-1-99	6
Spring Creek	1.5 miles west of Tetonia (R45E T6N S 30)	7-1-99	8
Badger Creek	~2.5 miles east of Felt (R45E T6N S10)	7-1-99	3
Badger Creek	2 miles north of Felt, 2.5 miles west of Highway 32 (R44R T7N S26)	7-1-99	6
Horseshoe Creek	Near confluence with Teton River (R44E T5N S12)	7-1-99	7
Packsaddle Creek	~0.5 mile northeast of Caribou-Targhee NF boundary (R44E T5N S8)	7-1-99	4
Teton River	Bates Bridge (R45E T4N S5)	6-23-99	11
Teton River	Rainer Campground (R45E T5N S13)	7-1-99	8
Teton River	Cache Bridge (R45E T5N S12)	7-1-99	13
Teton River	Harrop s Bridge at Highway 33 (R44E T6N S23)	7-1-99	8
Moody Creek	Moody Creek Elbow (R41E T6N S34)	6-10-99	57
Moody Creek	0.5 mile south of 2000N, 6000E (R41E T6N S17)	6-10-99	204
Moody Creek	Intersection of 2000N, 4000E (R40E T6N S12)	6-10-99	70
North Fork Teton R.	~1.5 miles west of Forks (R40E T7N S36)	6-10-99	14

Stream	Location	Date Sampled	Turbidity (NTU)[1]
South Fork Teton R.	North of Teton (R41E T7N S31)	6-10-99	16
South Fork Teton R.	1 mile south and 0.5 mile east of Sugar City on 2000N (R40E T6N S10)	6-10-99	17
South Fork Teton R.	In Rexburg at USGS[3] gage (R40E T6N S20)	6-10-99	29
South Fork Teton R.	West of Rexburg on Hibbard Road (R39E T6N S24)	6-10-99	22

[1]Nephelometric turbidity unit
[2]U.S. Forest Service
[3]U.S. Geological Survey

Nutrient Data

Water samples collected by the USGS at gage station 13055000, *Teton River near St. Anthony*, were analyzed for nutrients twice in water years 1976, 1980, and 1981; bimonthly in water year 1990; approximately monthly in water years 1993, 1994, and 1995; and monthly from April through October in 1999. These samples were consistently analyzed for total phosphorus and dissolved $NO_2 + NO_3$ (Appendix J), and sometimes for dissolved phosphorus, dissolved orthophosphorus, dissolved NO_2, and/or dissolved ammonia.

Water quality data from the *Teton River near St. Anthony* gage station indicate that total phosphorus concentrations originating in the subbasin upstream of the North and South Forks of the Teton River are well below the value of 0.1 mg/L recommended by the EPA for streams that do not flow into lakes. More than 96% of samples contained less than 0.05 mg/L total phosphorus, and only 2% contained concentrations greater than 0.1 mg/L. One of these samples, collected in October 1977, contained more than ten times the typical concentration, indicating that it was an aberrant measurement. In contrast, the concentrations of dissolved $NO_2 + NO_3$ equaled or exceeded the target concentration of 0.3 mg/L in more than half (38 of 72) of the samples analyzed. Concentrations of $NO_2 + NO_3$ ranged from 0.06 to 1.0 mg/L, and fluctuated in a regular pattern over time. Figure 19 illustrates this pattern using data collected from December 1992 through September 1996: concentrations of $NO_2 + NO_3$ are highest from October through April, decline to their lowest levels in June, then begin to increase slightly in August and September. An analysis of data from all years showed that concentrations 0.3 mg/L were measured during all months except June.

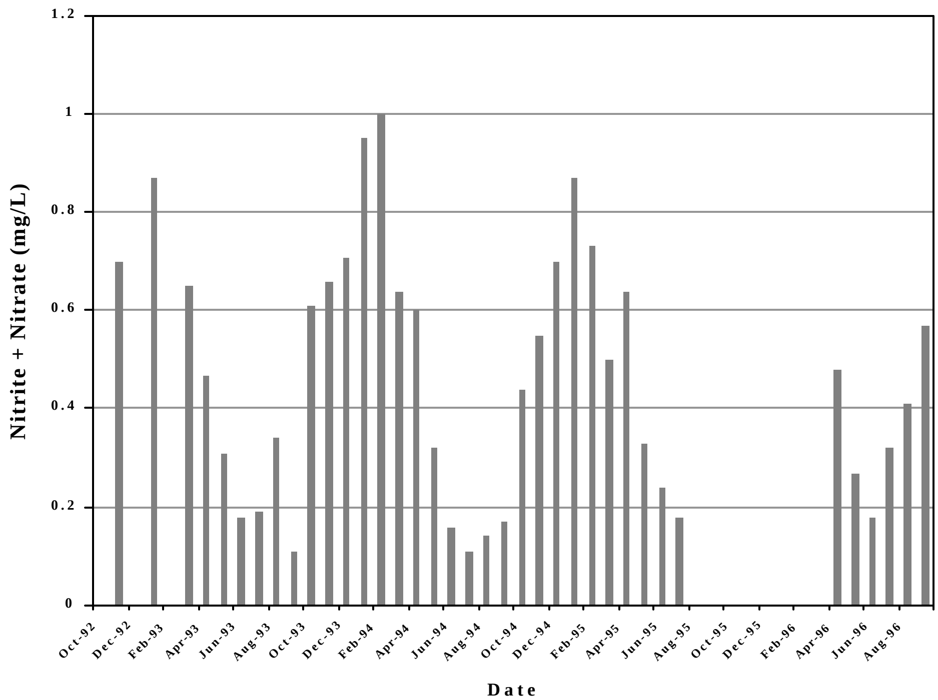

Figure 19. Concentrations of $NO_2 + NO_3$ in samples of water collected from December 1992 through September 1996 by the U.S. Geological Survey at the *Teton River near St. Anthony* gage station.

Nutrient data for other locations also indicate that concentrations of phosphorus in the subbasin are below the criterion of 0.1 mg/L set by the EPA, whereas concentrations of $NO_2 + NO_3$ often exceed the target of 0.3 mg/L. The largest data set for any location other than the *Teton River near St. Anthony* gage has been collected by the TSCD as part of the South Bitch Creek State Agricultural Water Quality Project (SAWQP). This project includes a long-term water quality monitoring component for the purpose of evaluating the effectiveness of agricultural best management practices in the Bitch Creek subwatershed. Water samples were collected approximately twice monthly, when sites were accessible, from May 1995 through May 1998 to establish baseline water quality conditions. More than 60 samples were collected upstream of cultivated agricultural lands at the forest boundary and downstream at the mouth of Bitch Creek near its confluence with the Teton River (Appendix K). The results of monitoring indicate that:

1. Concentrations of total phosphorus ranged from <0.01 mg/L to 0.1 mg/L in Bitch Creek at the forest boundary, and from <0.01 to 0.13 mg/L in Bitch Creek at its mouth. Concentrations in only three percent of the samples exceeded 0.1 mg/L, and concentrations in only 21% of the samples exceeded the detection level of 0.05 mg/L.

2. Concentrations of total phosphorus in Bitch Creek at the forest boundary were comparable to concentrations at the mouth, indicating that agriculture was not a significant source of phosphorus in the subwatershed. Two samples (3%) collected at each site exceeded 0.1 mg/L total phosphorus, 10 of 60 (16.7%) samples collected at the forest boundary equaled or exceeded 0.05 mg/L total phosphorus, and 16 of 62 (25.8%) samples collected at the mouth equaled or exceeded 0.05 mg/L total phosphorus.

3. Concentrations of $NO_2 + NO_3$ were generally higher in water collected at the mouth of Bitch Creek than in water collected at the forest boundary, indicating that agricultural practice is a source of nitrogen in the subbasin. More than 80 percent of the samples collected at the forest boundary contained concentrations less than 0.1 mg/L $NO_2 + NO_3$, compared with only 23% of the samples collected at the mouth. Concentrations ranged from <0.1 mg/L to 1.23 mg/L at the forest boundary and from 0.03 mg/L to 1.94 mg/L at the mouth. By comparison, median $NO_2 + NO_3$ concentrations in surface water collected from the Snake River at Flagg Ranch, Wyoming, an area considered unaffected by all nitrogen sources except precipitation and domestic septic systems, was less than 0.1 mg/L as N, and median total nitrogen concentration was only about 0.35 mg/L (Clark 1994, as cited in Rupert 1996).

4. Because more than 80 percent of the samples collected at the forest boundary contained concentrations of less than 0.1 mg/L $NO_2 + NO_3$, the concentrations in four samples collected at this site in September and October 1995 (1.18 mg/L, 0.55 mg/L, 1.23 mg/L, and 0.41 mg/L) appear anomalous. Less than two weeks before and after these samples were collected, concentrations of $NO_2 + NO_3$ were less than 0.05 mg/L. Furthermore, the abrupt increase and decrease in concentrations did not occur at the same time in 1996. Drewes (1993) reported a concentration of 1.1 mg/L $NO_2 + NO_3$ in a sample collected on Bitch Creek at the forest boundary. But a sample collected the same day from the mouth of Bitch Creek contained only 0.003 mg/L, indicating the possibility that the samples were incorrectly labeled or the results inaccurately reported. The validity of these results is important because concentrations measured downstream in samples collected on the same dates (1.94 mg/L, 1.65 mg/L, and 1.73 mg/L) were substantially higher than concentrations measured at any other time on Bitch Creek. If these results were correct, they indicate sources of nitrogen other than cultivated agriculture.

5. Data collected at the forest boundary and the mouth of Bitch Creek show the same trend in concentrations of $NO_2 + NO_3$ as the data collected at the USGS gage station, but because the peak concentrations at the forest boundary are much lower than at the mouth, this trend is less apparent (Figure 20).

6. Concentrations of $NO_2 + NO_3$ in samples collected at the mouth of Bitch Creek generally exceeded 0.3 mg/L from August through November and February through April (sampling was not conducted in December or January because sites were inaccessible), and were less than 0.3 mg/L from May through July (Figure 20). This trend differs from the trend observed for samples collected at the *Teton River near St. Anthony* gage in that June was the only month in which all Teton River samples contained concentrations less than 0.3 mg/L.

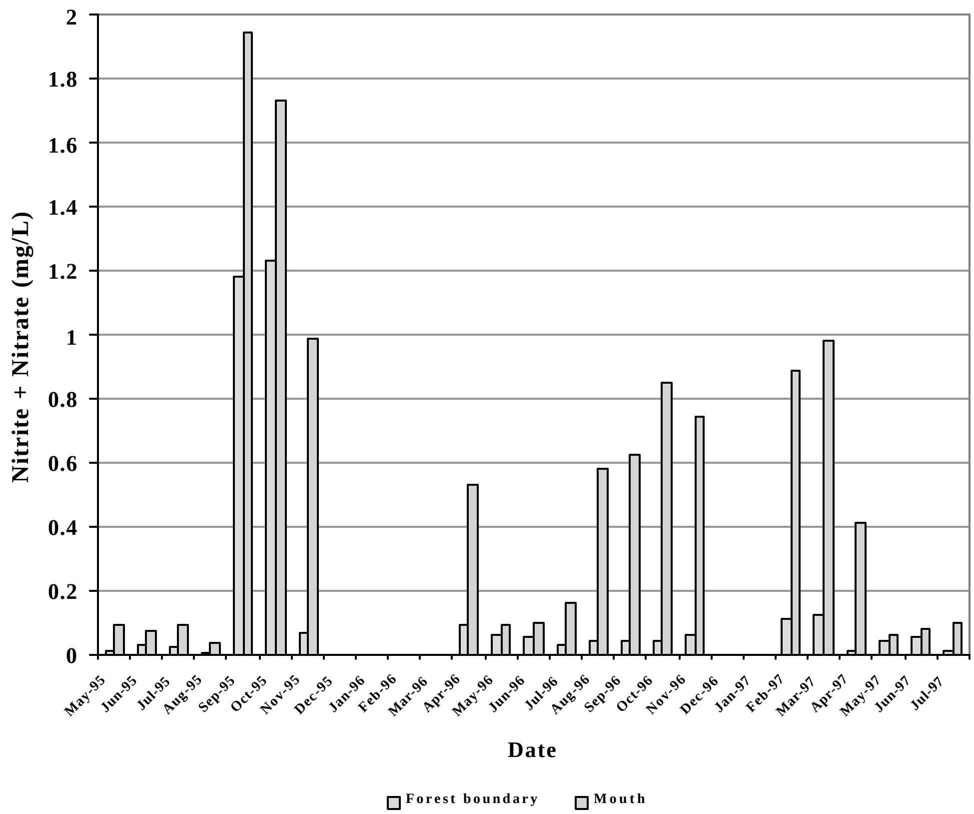

Figure 20. Concentrations of $NO_2 + NO_3$ in samples of water collected from Bitch Creek at the National Forest boundary and mouth from May 1995 through May 1998.

Concentrations of $NO_2 + NO_3$ greater than 0.3 mg/L have been reported for a variety of sampling locations along the Teton River, including the upper Teton River and North Fork Teton River. The Soil Conservation Service sampled the Teton River upstream of the North and South Forks near the location of the *Teton River near St. Anthony* gage, and downstream of the forks at four locations. This sampling was done as part of a study to evaluate habitat recovery within the channel of the North Fork following collapse of the Teton Dam (SCS 1982). Samples were collected on 18 days over a period of 44 months, but only three of those days occurred during May, June, and July, the months during which the lowest $NO_2 + NO_3$ concentrations were observed for samples collected at the *Teton River near St. Anthony* gage. Results of analyses were reported for NO_2 separately from NO_3, as opposed to combined $NO_2 + NO_3$. Fewer than 25% of the samples contained concentrations of less than 0.3 mg/L NO_3, though the low number of samples collected during summer months may have skewed this result. It is interesting to note that concentrations of NO_3 were sometimes lower at downstream sites, despite contributions of irrigation return flows from the Farmers Friend, Fall River, Wilford, and Salem Union Canals. Concentrations of orthophosphorus were greater than 0.1 mg/L on three occasions (December 27, 1976; January 3, 1977; and July 3, 1980), but generally concentrations were much less than 0.05 mg/L.

Concentrations of NO_3 in samples collected at several locations in the upper Teton River over a period of 13 years show the same trends as concentrations in samples collected by the USGS at the *Teton River near St. Anthony* gage. Drewes (1987 and 1993) collected samples of Teton River water at five sites located from above the confluence of Horseshoe Creek (Cache Bridge) to below the confluence of Canyon Creek (Appendix L, Table L-1). Only six of 37 samples contained concentrations of $NO_2 + NO_3$ less than 0.3 mg/L, and four of these samples were collected in June. Approximately ten years later, Manguba (1999), Thomas *et al.* (1999), and Minshall (2000) collected samples at several locations on the Teton River, including two sampled by Drewes (Cache Bridge and Harrop s Bridge). Once again, their data indicate that concentrations of $NO_2 + NO_3$ in the Teton River typically exceed 0.3 mg/L in all months except June. The concentrations of $NO_2 + NO_3$ reported for 1997 often exceeded 1 mg/L, and the highest concentration of $NO_2 + NO_3$ reported for the entire Teton Subbasin (2.14 mg/L) was for a sample collected in September 1997 at Bates Bridge (Appendix L, Table L-1). Because these data are for sites extending from the upper Teton River to the lower Teton River, they also reveal that concentrations of $NO_2 + NO_3$ in the Teton River appear to decrease in a downstream direction, with lowest concentrations occurring in the North and South Forks of the Teton River (Tables 21 and 22).

Most of the nutrient data available for tributaries of the Teton River were reported by Drewes (1987, 1988, and 1993), and are for samples collected from 1986 through 1990 (Appendix L, Tables L-2 and L-3). Precipitation, runoff, and surface water flows were considered below average during this period, and numerous data gaps occurred because lack of flow precluded sample collection. However, a comparison of data reported by the TSCD (Appendix K) and Drewes (Appendix L, Table L-2) show similarities for samples collected at Bitch Creek near the confluence with the Teton River for all months except October. The TSCD reported $NO_2 + NO_3$ concentrations ranging from 0.74 mg/L to 1.73 mg/L in October of 1995 and 1996, whereas Drewes reported a concentration of only 0.003 mg/L in October 1988.

Coincidentally, the concentration of $NO_2 + NO_3$ reported by Drewes (1993) for a sample collected on the same date on Bitch Creek at the forest boundary was 1.13 mg/L (Appendix L, Table L-2). This value is consistent with concentrations reported by the TSCD for Bitch Creek at the confluence with the Teton River, and indicates that the results reported by Drewes (1993) for Bitch Creek in October may have been transposed or the samples incorrectly labeled when they were collected. Assuming this interpretation is correct, the data shown in Table 22 and Appendix L, Table L-2 indicate that 1) concentrations of $NO_2 + NO_3$ increased in Badger Creek between the forest boundary and its confluence with the Teton River in a manner similar to that which occurred in Bitch Creek, 2) the $NO_2 + NO_3$ concentration exceeded 0.3 mg/L in Canyon Creek only once during a period of more than 36 months, 3) $NO_2 + NO_3$ concentrations in Canyon Creek did not fluctuate seasonally in the same manner as concentrations in Bitch or Badger Creeks, and 4) $NO_2 + NO_3$ concentrations were typically far below 0.3 mg/L in streams originating in the Big Hole Mountains (Horseshoe, Packsaddle, Milk, and Canyon Creeks) and in Spring and South Leigh Creeks.

Table 21. Concentrations of NO_3 (mg/L as N) in samples collected from Fox Creek and the upper Teton River in 1997, 1998, and 1999.[1] Concentrations of NO_3 greater than 0.3 mg/L are highlighted with italic type.

Date	Fox Creek near Confluence with Teton River	Teton River at Bates Bridge	Teton River at Rainer Campground	Teton River at Cache Bridge	Teton River at Highway 33 (Harrop's Bridge)
6/4/97		0.21		0.09	0.03
6/25/97		*0.38*		0.22	0.17
7/16/97		*0.53*		*0.58*	*0.62*
8/6/97		*1.53*		*0.93*	*0.94*
8/27/97		*1.50*		*0.91*	*0.83*
9/17/97		*2.14*		*1.05*	*1.02*
10/8/97		*1.38*		*1.23*	*1.07*
3/4/98		*1.65*		*1.01*	*0.68*
4/29/98		*1.22*		*0.39*	*0.57*
8/1/98	*0.85*		*0.86*		*0.51*
6/99	*0.789*		0.266		0.022
8/12/99	*1.192*		*0.842*		*0.590*
10/3/99	*1.154*				*0.312*

[1]Data for Teton River at Bates Bridge, Teton River at Cache Bridge, and Teton River at Highway 33 (Harrop's Bridge) prior to 8/1/98 from INEEL (Manguba 1999); 8/1/98 data from Thomas *et al*. (1999); all other data from Minshall (2000).

Table 22. Concentrations of NO_3 (mg/L as N) in samples collected from the Teton River Canyon and North and South Forks Teton River in 1998 and 1999.[1] Concentrations of NO_3 greater than 0.3 mg/L are highlighted with italic type.

Date	Teton River at Spring Hollow	Teton River at Teton Dam Site	South Fork Teton River	North Fork Teton River
8/1/98	*0.66*	*0.54*	0.29	0.22
6/99	0.157	0.156	0.128	0.184
8/12/99	*0.806*	*0.694*	*0.475*	
10/3/99		*0.801*		

[1]8/1/98 data from Thomas *et al*. (1999); all other data from Minshall (2000).

The seasonal changes in $NO_2 + NO_3$ concentrations indicate that concentrations decrease when water temperatures are warm and plants are using available nitrogen and flows are at their highest levels and dominated by snowmelt. Conversely, concentrations increase when 1) low temperatures limit plant growth and utilization of nitrogen, 2) decomposition of accumulated plant material is releasing nitrogen to the water column, and 3) low surface water flows combined with recharge of ground water from the previous runoff may allow the release of ground water and its nitrogen to the river channel.

Sources of Nitrogen in the Teton Subbasin Rupert (1996) analyzed nitrogen input and loss for the upper Snake River Basin, and calculated the amount of residual nitrogen produced in each county within the basin in 1990. He based his analysis on assumptions that included the following:

1. The primary nonpoint sources of nitrogen input to the basin are cattle manure, fertilizer, legume crops, precipitation, and domestic septic systems.

2. Precipitation is the only major source of naturally occurring nitrate (NO_3) in the basin and contains from 0.18 to 0.27 mg/L total N.

3. The average dairy cow produces between 0.41 and 0.59 lb/day total nitrogen, the average beef cow produces between 0.34 and 0.43 lb/day total nitrogen, alfalfa produces between 60 lb/acre and 225 lb/acre total nitrogen, and domestic septic systems produce between 0.01 and 0.04 lb per person per day total nitrogen.

4. Nitrogen loss occurs through storage and application of cattle manure, crop uptake, and decomposition of previous-year nonleguminous crop residue.

Because of insufficient data, processes involving native vegetation were not considered in the analysis, nor were losses due to denitrification of fertilizer or domestic septic system effluent.

Carryover of total nitrogen from previous years was not included in the analysis, though the author noted that carryover could cause all of the residual nitrogen estimates to increase.

The mean, maximum, and minimum residual nitrogen values calculated by Rupert (1996) for counties located in and around the Teton Subbasin, and for counties within the upper Snake River Basin that produced the highest (Twin Falls) and lowest (Power) residual nitrogen values are listed in Table 23. Based on mean residual nitrogen values for Madison County and Teton County, Idaho, approximately 4,408 tons of excess nitrogen were produced in the Teton Subbasin in 1990. According to Rupert (1996), "[t]his residual total nitrogen is available for runoff to surface water or leaching to ground water." He also noted that in three out of four counties where mean values of residual nitrogen were highest (Cassia, Gooding, and Twin Falls), eutrophication in the Snake River was evident and ground water from many wells contained anomously high nitrate concentrations.

Table 23. Approximate ranges of residual nitrogen estimated by Rupert (1996) for counties in the Teton Subbasin for water year 1990. Counties with the highest (Twin Falls) and lowest (Power) residual amounts of nitrogen in the upper Snake River Basin are shown for comparison.[1]

County	Mean Residual Nitrogen		Maximum Residual Nitrogen		Minimum Residual Nitrogen	
	Millions of Kilograms	Tons[2]	Millions of Kilograms	Tons	Millions of Kilograms	Tons
Madison	2	2,204	4.5	4,959	-0.5	-551
Teton, ID	2	2,204	3.75	4,133	0.25	276
Teton, WY	4	4,408	5	5,510	3	3,306
Fremont	2.5	2,755	5.75	6,337	-0.75	-827
Twin Falls	8.75	9,643	16	17,632	1	1,102
Power	-2.5	2,755	1.25	1,378	-6.25	6,888

[1]Rupert (1996) displayed data graphically instead of numerically, so the data shown in this table are approximations of values contained in Figure 4 of his report.
[2]Calculated by multiplying amount in kilograms by 1.102×10^{-3}.

For the entire upper Snake River Basin, Rupert (1996) calculated that 45 percent of residual nitrogen originated from fertilizer, 29 percent originated from cattle manure, 19% originated from legume crops, 6 percent originated from precipitation, and less than 1% originated from domestic septic systems. But he observed that input from fertilizer, cattle manure, and legume crops varied widely among counties, reflecting differences in land use practices, cropping patterns, and numbers of dairies and feedlots. For the six-county region that included Madison County and Teton County, Idaho, approximately 58% of residual nitrogen originated from fertilizers, 19% originated from cattle manure, 19% from legume crops, less than 5% from precipitation, and less than 1% from domestic septic systems. Rupert (1996) combined Fremont, Madison, Teton (ID), Jefferson, Bonneville, and Bingham Counties into “Central Counties.” Teton, Sublette, and Lincoln Counties, Wyoming, and Caribou, Bannock, and Power Counties, Idaho, were combined into the “Southern and Eastern Counties.” For the six-county region that includes Teton County, Wyoming, approximately 26% of residual nitrogen originated from fertilizers, 40% originated from cattle manure, 21% originated from legume crops, 13% originated from precipitation, and much less than 1% originated from domestic septic systems. Rupert’s estimate of the amount of nitrogen originating from fertilizer in Teton County, Idaho, compares well with the estimate made in the *Teton River Basin Study* (TSCD 1992). Based on the assumption that each ton of cropland-generated sediment contained three pounds of nitrogen, the *Teton River Basin Study* (TSCD 1992) estimated that 226 tons of nitrogen were generated from cropland in the area of the Teton Subbasin upstream of, and including, the Badger Creek and Packsaddle Creek subwatersheds. The amount of residual nitrogen in the Teton River Basin originating from fertilizer was calculated by dividing the residual nitrogen for Teton County, Idaho (Table 23) by half to adjust for acreage. This figure was multiplied by Rupert's figure of 58 percent to adjust for the amount of nitrogen originating from fertilizer. The results ranged from 80 to 1,199 tons with a mean of 639 tons. The amount of sediment-associated nitrogen estimated in the *Teton River Basin Study* was within this range although it was only about one-third of the mean value (i.e., 226 tons/639 tons). These results indicate that the amount of nitrogen originating from fertilizer in the Teton Subbasin is probably somewhat less than the percentage estimated by Rupert (1996).

Clark (1994), in an analysis of nutrient data collected in the upper Snake River Basin from 1980 through 1989, observed that "concentrations of nitrite plus nitrate were largest in samples collected at the mouths of tributary drainage basins with a large amount of agricultural activity." Concentrations of $NO_2 + NO_3$ at stations categorized as "unaffected or minimally affected by urban or agricultural land use" ranged from 0.025 to 0.65 mg/L as N, whereas concentrations at stations categorized as "agriculturally affected" ranged from 0.125 to 3.2 mg/L as N (Table 24). Furthermore, seasonal variations in concentrations of $NO_2 + NO_3$ differed between these two categories of sampling stations. The median $NO_2 + NO_3$ concentrations increased from 0.1 mg/L in winter (January to March) to 0.14 mg/L in spring (April to June) at unaffected stations, but decreased from 1.4 mg/L to 1 mg/L at affected stations (Table 24).

Clark (1994) speculated that residual nitrogen flushed from soils during snowmelt was responsible for the increased springtime concentration of $NO_2 + NO_3$ at agriculturally unaffected stations, and that "the combined effects of dilution from increased streamflow and uptake of excess nitrogen by aquatic plants" was responsible for the decreased springtime concentrations at affected stations. Furthermore, he states that:

> As streamflows decrease later in the summer, ground water, which is a source of nitrogen to streams in part of the Snake River Basin, becomes an increasingly important component of streamflow, and nitrite plus nitrate and total nitrogen concentrations in the water column increase. In addition, aquatic plants die and mineralize, contributing additional nitrogen to streams.

Table 24. Median seasonal concentrations of $NO_2 + NO_3$ reported by Clark (1994) for "agriculturally unaffected" and "agriculturally affected" sampling stations in the upper Snake River Basin, and median seasonal concentrations of $NO_2 + NO_3$ calculated for three sampling stations within the Teton Subbasin.

Sampling Station	Median Concentration of $NO_2 + NO_3$ (mg/L as N)[1] [10th, 90th Percentile] or {Range} (n)			
	Jan. - March	April - June	July - Sep.	Oct. - Dec.
Unaffected Stations[2]	0.1 [0.1, 0.45] (48)	0.14 [0.1, 0.65] (49)	0.1 [0.05, 0.25] (59)	0.1 [0.025, 0.2] (46)
Affected Stations[3]	1.4 [0.7, 3.2] (77)	1 [0.25, 1.5] (84)	1.65 [0.125, 2] (89)	1.75 [0.75, 2.7] (74)
Bitch Creek at Mouth[4]	0.89 [0.52, 1.0] (15)	0.11 [0.06, 0.58] (33)	0.28 [0.09, 1.65] (15)	0.92 [0.74 - 1.73] (6)
Teton River at Highway 33[5]	0.68 (1)	0.1 [0.02 - 0.57] (4)	0.73 [0.51 - 1.02] (6)	0.69 [0.31 - 1.07] (2)
Teton River at St. Anthony[6]	0.73 [0.5, 1] (11)	0.22 [0.1, 0.48] (28)	0.26 [0.08, 0.57] (22)	0.61 [0.09, 0.71] (11)

[1]Clark (1994) displayed data graphically instead of numerically, so data shown in this table are approximations of values contained in Figures 23 and 24 of his report.
[2]Examples of stations categorized as "unaffected or minimally affected by urban or agricultural land use" are the Snake River near Flagg Ranch, WY, and Rock Creek near Rock Creek, ID.
[3]Examples of stations categorized as "agriculturally affected" are the Henry's Fork near Rexburg, Blackfoot River near Blackfoot, and Rock Creek near Twin Falls.
[4]Calculated using data contained in Appendix K
[5]Calculated using data contained in Appendix L, Table L-1
[6]Calculated using data contained in Appendix J

Therefore, according to Clark (1994), the concentration of $NO_2 + NO_3$ in surface water in the upper Snake River Basin appears to be a function of its concentration in ground water. Precipitation, surface runoff, and aquatic plant growth and senescence are secondary factors that modify the concentration of $NO_2 + NO_3$ in surface water on a seasonal basis.

The median seasonal concentrations of $NO_2 + NO_3$ at three sampling locations in the Teton Subbasin were calculated using the data shown in Table 21, Appendix J, and Appendix K. The results are listed in Table 24 along with the concentrations reported by Clark (1994) for agriculturally affected and unaffected stations. As expected, the seasonal concentrations of $NO_2 + NO_3$ for sites in the Teton Subbasin correspond most closely to concentrations for agriculturally affected stations, with the highest median concentrations occurring in the fall and winter and the lowest concentrations occurring in the spring. The median concentration of $NO_2 + NO_3$ in samples collected from the Teton River at Highway 33 was highest from July through September whereas at Bitch Creek and the Teton River near St. Anthony, concentrations of $NO_2 + NO_3$ remained similar to springtime concentrations. Although this comparison was based on relatively few samples from the Highway 33 site, these results indicated that the hydrological, chemical, and biological processes that influence nitrogen concentrations in surface water upstream of Highway 33 differ from the processes that influence concentrations downstream.

Because of the contribution of spring flows to surface water flows in the upper Teton Subbasin, it is reasonable to assume that concentrations of nitrate in ground water strongly influence surface water quality. From the headwaters of the Teton River to the confluence of Badger Creek, all of the streams that discharge to the river year-round are spring-fed. Data collected by DEQ for public drinking water wells in the Teton Subbasin show that concentrations of nitrate in ground water east of Harrop's Bridge at Highway 33 range from less than detection level (0.05 mg/L as N) to 3 mg/L as N. The maximum nitrate concentrations measured in water samples from eleven wells were less than 1 mg/L as N, whereas the maximum concentrations in water samples from nine wells ranged from 1 mg/L to 3 mg/L as N. These values are consistent with concentrations measured in the Teton River, and indicate that the springs supplying surface water flows originate in the same aquifers that supply drinking water.

Downstream of Harrop's Bridge in the vicinity of Rexburg, nitrate concentrations in water samples taken from public drinking water systems are generally much higher than in the Teton Valley. These concentrations range from 1.5 mg/L to 11 mg/L as N (Figure 21). Concentrations in surface water in the vicinity of Rexburg are not as high as concentrations in ground water because the direction of water movement is from the surface down to the aquifer instead of from the aquifer up to the surface. Protection of ground water from nitrate contamination is important because of the potential human health effects, particularly in infants. The maximum contaminant level (MCL) for nitrate in drinking water, established by the EPA to protect human health, is 10 mg/L as N. As discussed in an earlier section of this assessment, the concentration of nitrate that may produce ecological effects in surface water is only about one-tenth of the MCL.

Fate of Residual Nitrogen in the Teton Subbasin Rupert (1996) described the fate of excess nitrogen in the region of the upper Snake River Basin between Milner Dam and King Hill as follows:

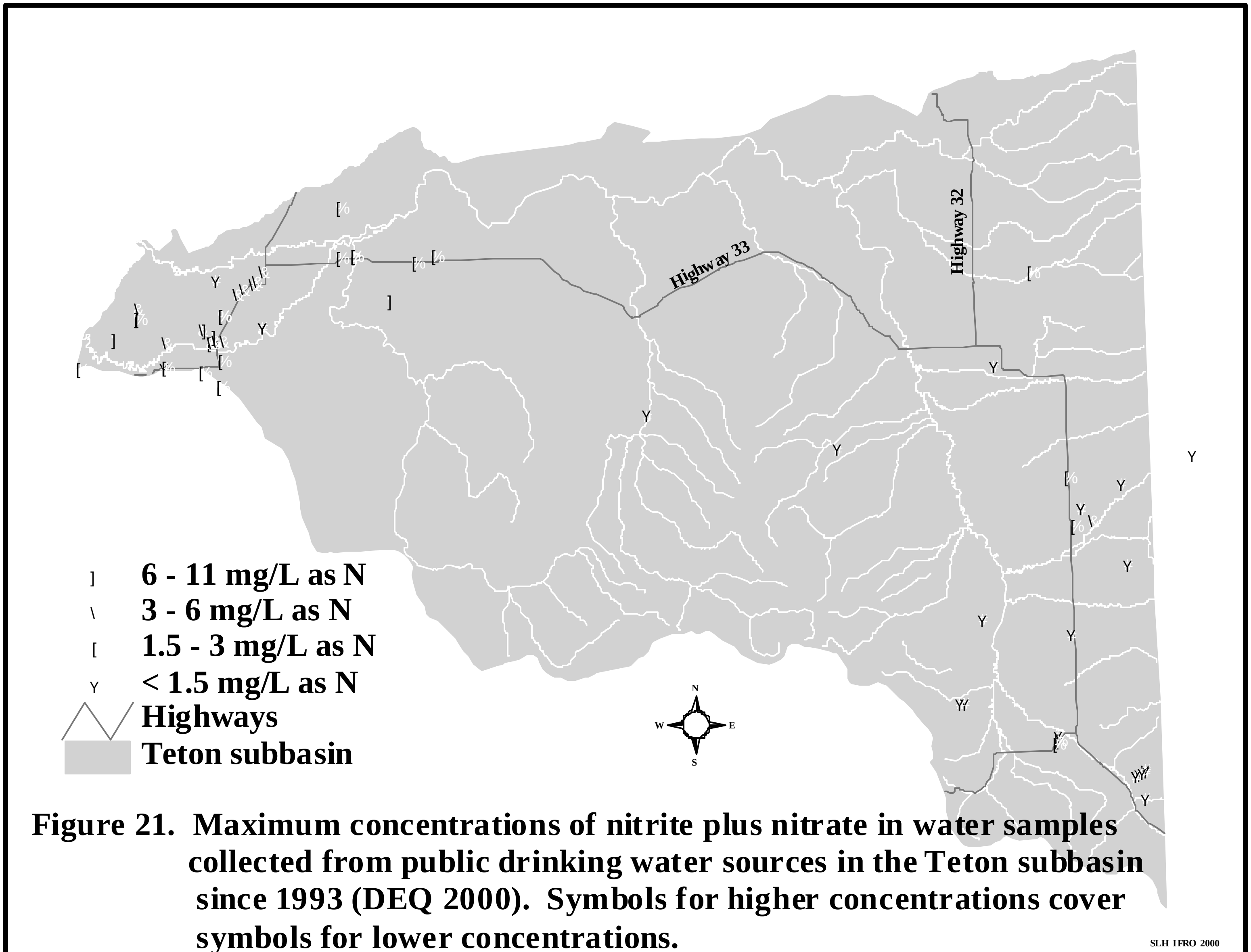

Figure 21. Maximum concentrations of nitrite plus nitrate in water samples collected from public drinking water sources in the Teton subbasin since 1993 (DEQ 2000). Symbols for higher concentrations cover symbols for lower concentrations.

> This excess nitrogen probably is utilized by aquatic vegetation in the Snake River, stored as nitrogen in soil, stored as nitrate in the ground water, and utilized by noncrop vegetation. Falter and Carlson (1994...) showed that aquatic vegetation removes nitrogen from the water column in the Snake River. Clark (1994) also suggested that aquatic vegetation removes nitrogen in the river during the growing season. Some of the nitrogen supplied by cattle manure, fertilizer, legume crops, precipitation, and domestic septic systems can be stored in the soil and is not available for runoff or leaching to surface and ground water. Another fraction of this nitrogen can leach to ground water and eventually be discharged through the springs. Additional nitrogen is utilized by vegetation other than cultivated crops, such as vegetation growing along irrigation canals and riverbanks. Nitrogen can also be lost through additional denitrification processes not accounted for in this report.

This description is applicable to excess nitrogen in the Teton Subbasin, though it must be expanded to include the influence of extensive wetlands in the Teton Valley. The U.S. Fish and Wildlife Service has classified 9% of Teton County as wetlands (Peters *et al.* 1993).

According to Mitsch and Gosselink (1993), "wetlands serve as sources, sinks, or transformers of chemicals, depending on the wetland type, hydrologic conditions, and the length of time the wetland has been subjected to chemical loading." It's possible for the wetlands along the Teton River to function as sinks and sources of nitrogen, depending on hydrologic conditions. In a study of a riverine marsh in Wisconsin (Klopatek 1977), concentrations of nitrogen followed a predictable seasonal trend. Concentrations decreased during the algae and macrophyte growing season and increased in the fall when nitrogen was presumably released from decaying plants. The data indicate nitrogen concentrations in the Teton River decrease an order of magnitude from the upper river near Fox Creek to the lower reaches of the North and South Forks. Possible reasons for this include a net loss of nitrogen to the wetland communities of the upper Teton Valley and dilution by surface water.

Although it is difficult to quantify the amount of nitrogen moving between environmental compartments such as soil and water, elevated ground water concentrations clearly indicate that nitrogen applied to soils in the Teton Subbasin has migrated to the aquifers underlying the subbasin. According to Parliman (2000), concentrations of nitrate in Idaho's ground water prior to land and water development were probably less than 1 mg/L as N. Sampling conducted from 1995 through 1999 indicated that the median concentration of nitrate in Idaho ground water was 1.4 mg/L as N, and ranged from less than 0.5 mg/L to 100 mg/L as N. Samples collected from wells and springs throughout the Teton Subbasin during the same period produced concentrations as high as 38 mg/L as N in the lower subbasin near Rexburg (Parliman 2000). Throughout Idaho, DEQ has designated 33 ground water quality management areas because of the degraded quality of aquifers used as drinking water sources. Four management areas are located in the Henry's Fork basin; two of these overlap the Teton Subbasin. One area extends from Ashton into the northwest corner of Teton County; another is centered in the Hibbard area near Rexburg (DEQ 2001).

Temperature Data for the Teton Canyon Segment of the Teton River

The most highly altered stream segment in the Teton Subbasin extends through the Teton Canyon from Bitch Creek to the Teton Dam site. This area was the location of the first phase of the Teton Basin Project, which was intended to accomplish the following goals: 1) supply supplemental water to 111,210 acres of irrigated land in the Fremont-Madison Irrigation District, 2) produce hydroelectricity, 3) provide for recreation at the reservoir, 4) mitigate project-caused losses of fish and wildlife, and 5) control flooding (Stene 1996). The 17-mile-long reservoir behind Teton Dam began filling on October 3, 1975. When the dam failed on June 5, 1976, the reservoir was only 22.6 feet below the planned maximum elevation, and water behind the dam reached a depth of 272 feet. As the dam collapsed, approximately 250,000 acre-feet of water and 4 million cubic yards of embankment material flowed past the dam structure in only six hours (Randle *et al.* 2000).

The rapid drawdown of the reservoir activated more than 200 landslides along the reservoir rim. About 1,460 acres of canyon slopes were submerged by the reservoir and 500 acres, or 34 percent, failed. Approximately 3.6 million cubic feet of material moved downslope to the canyon floor, with some material reaching and blocking the river or burying the original river channel. In addition to the Teton River Canyon, approximately three miles of the canyon of lower Canyon Creek were also affected by the dam's collapse (Randle *et al.* 2000).

From 1997 through 1999, the BOR conducted studies of the Teton River between the Teton Dam site and the Felt Dam Powerhouse, 19 miles upstream of the dam site. The objectives of the studies were to document the current physical and biological condition of the Teton River and canyon, and to provide technical information to aid the BOR in directing management of BOR lands. Data collected during the studies include the following: new aerial and ground photographs, measurements of riverbed topography, water-surface elevations, preliminary particle size analysis of landslide material, and bed-material particle size distributions (Randle *et al.* 2000); air and water temperatures (Bowser 1999); and information regarding the riparian vegetation community (Beddow 1999, as cited in Randle *et al.* 2000).

The effects of the landslides on river and canyon morphology are described by Randle *et al.* (2000) as follows:

> Within the study reach from Bitch Creek to Teton Dam, the Teton River canyon is narrowest at the upstream end and tends to become progressively wider in the downstream direction. As the canyon widens out, terraces along both banks of the river widen out also. Upstream from the confluence with Canyon Creek, the Teton River canyon was narrow enough that the 1976 landslide debris fans typically reached the river channel. Those debris fans formed new rapids in some locations and enlarged pre-existing riffles in other locations. ...27 rapids or riffles and pools have persisted in the reach upstream from Canyon Creek (17 rapids and 1 riffle between Canyon Creek [river mile 5] and Spring Hollow [river mile 12.1] and 7 rapids and 2 rapid and riffle combinations upstream from Spring Hollow). Landslides also deposited debris in river-channel pools upstream from some of these rapids. Downstream from Canyon Creek, the Teton River canyon was wide

> enough that the landslide debris was deposited on the surface of the adjacent river terraces and typically did not reach the river channel. Therefore, the river channel was not significantly constricted by landslides downstream from Canyon Creek, and the hydraulics are relatively the same as in predam conditions.
>
> The 1976 landslides had the greatest impact on the Teton River channel in the 2-mile reach upstream from Canyon Creek, between [river mile] 5.3 and [river mile] 7.4. In this reach, there is no evidence of deep pools having been present in 1972. However, there are four new major rapids and pools (24, 25, 26, and 27) in this reach today, with pool depths ranging from 8 to 19 feet.

Changes in river morphology were also caused by excavation of the channel and terraces for materials to construct the dam (Randle *et al.* 2000). Approximately 1.1 miles upstream from the dam site, the river was characterized by a meandering channel and broad, flat terraces. The gravel terraces were excavated, creating two deep pools connected by a narrow channel. These pools are commonly referred to as borrow ponds and currently contain a total volume of 1,000 acre-feet of water. The downstream pond has a maximum depth of 43 feet and a maximum top width of 380 feet. The upstream pond has a maximum depth of 36 feet and a maximum top width of 760 feet. A portion of the river's flow bypasses the borrow ponds through a diversion channel that runs parallel to the ponds.

Bureau of Reclamation scientists speculated that the borrow ponds and numerous pools created by landslides had caused river water temperatures to increase (Bowser 1999). They tested this hypothesis in 1998 by deploying 20 temperature data loggers from Badger Creek to the bottom of the borrow ponds. Three data loggers recorded air temperatures and 17 recorded water temperatures from July 23 to September 9, 1998. Some of the data were unusable because the temperature loggers were affected by solar radiation or did not remain submerged in water. However, the data were sufficient for Bowser (1999) to conclude that

> [i]n general the new data shows a 2- to 4-degree Fahrenheit temperature rise between the Bitch Creek logger and the logger at the downstream end of the second borrow pond. ...[T]he majority of the temperature increase is approximately between data logger number 1 (upstream of rapid 14/downstream of pool 14) downstream from the 90 degree bend and data logger number 10 at Canyon Creek, rather than from the borrow ponds as might be suspected. This correlates with hydraulic modeling data that suggests this reach has by far experienced the greatest increase in water surface elevation compared to the pre-dam condition. In fact, the data suggests that the borrow ponds may actually lower water temperature as it passes through....

Randle *et al.* (2000) determined that the travel time of water flowing through the Teton Canyon from Bitch Creek to the confluence with Canyon Creek, with a typical July discharge of 1,000 cfs, has increased from eight hours prior to dam construction to 14 hours currently. They attribute this increase primarily to the formation of pool 4 and to the formation of new, large rapids between river miles 5.3 and 7.4. They also conclude that the travel time of water has not changed in the reach between Canyon Creek and the borrow ponds. Bowser (1999) reported a total travel time of 21 hours between Bitch Creek and the Teton Dam site for a discharge of 1,000 cfs.

According to Randle *et al.* 2000, "the construction and subsequent failure of Teton Dam has likely increased summer river water temperatures by 1 to 2 degrees F." This increase in river water temperature was attributed to increased travel time and the loss of riparian vegetation. Woody vegetation, including extensive cottonwood riparian forests, was removed from the reservoir area before it began filling with water. Following the collapse of Teton Dam, the reservoir basin was reseeded with reed canary grass (*Phalaris arundinacea*) to control surface erosion. Currently, the riparian area consists almost entirely of reed canary grass and is generally devoid of the types of riparian and woody vegetation that would shade the river from incident solar radiation.

The temperature data collected by the BOR in 1998 were analyzed by DEQ for violations of Idaho's temperature criteria for cold water aquatic life. Electronic data files were provided to DEQ by Mr. Steven Bowser of the Technical Service Center of the BOR. The numbers and dates of violations of the 22 ^{o}C instantaneous criterion and 19 ^{o}C daily average criterion were tabulated, then compared with the 90th percentile value for the maximum seven-day average air temperature. Because air temperatures influence water temperatures, *IDAPA 58.01.02.080.04* states that "exceeding the temperature criteria [for aquatic life use designations] will not be considered a water quality violation when the air temperature exceeds the 90th percentile of the seven (7) day average daily maximum air temperature calculated in yearly series over the historic record measured at the nearest weather reporting station." The seven-day average maximum air temperatures were calculated using historical data from the BOR's AgriMet station at Rexburg, accessed via the Internet at http://agrimet.pn.usbr.gov/%7Edataaccess/webarcread3.exe. Using data from 1987 through 2000, the 90th percentile of the seven-day average daily maximum air temperature was calculated to be 92.3^{o}F (33.5^{o}C). Based on records collected by the BOR at Spring Hollow (data logger 7), air temperatures exceeded this value on July 23, 26, 27, 28, and 31; August 6, 7, 13, 14, and 31; and September 5, 1998 (Appendix M). Therefore, exceedances of water quality criteria that occurred on these days were not in violation of water quality standards

Thirty-six temperature criteria exceedances occurred in 1998, but only half of these exceedances were violations of water quality standards (Table 25). The 18 violations occurred at only three locations, and 15 violations occurred between August 9 and August 18. Bowser (1999) noted that the water temperatures collected were directly and immediately influenced by air temperatures, as data loggers that did not remain submerged or were submerged but exposed to sunlight may have recorded inaccurately high temperatures. He also cautioned against making direct comparisons between data logger locations or among individual logger data over time due to differences in shading and submergence depth due to changing water surface profiles over time.

Table 25. Exceedances and violations of cold water aquatic life criteria in the Teton River Canyon, as determined using data provided by the Bureau of Reclamation.

Data Logger	Location	Number of Temperature Criteria Exceedances		Number of Temperature Criteria Violations[1]	
		22 °C Instantaneous	19 °C Daily Average	22 °C Instantaneous	19 °C Daily Average
6	Immediately Upstream of Confluence of Bitch Creek	9	0	7	0
BR-1	Spring Hollow	0	0	0	0
5	1st below Spring Hollow	0	0	0	0
3	2nd below Spring Hollow	0	0	0	0
8	3rd below Spring Hollow	0	0	0	0
NFB-2	4th below Spring Hollow	0	0	0	0
BR-HNT	5th below Spring Hollow	0	0	0	0
NFB-3	Linderman Dam	0	0	0	0
CC-2	1st below Linderman Dam	0	0	0	0
NFB-1	2nd below Linderman Dam	0	0	0	0
BR-4	3rd below Linderman Dam	Could not be determined: Data logger missing			
1	4th below Linderman Dam	0	0	0	0
CC-4	5th below Linderman Dam	0	2	0	0
4	6th below Linderman Dam	0	2	0	0
10	7th below Linderman Dam	8	9	5	3
DC-1	Top of Borrow Ponds	Could not be determined: Temperature exceeded 50 °C (122 °C) on August 4 and 13, indicating that data logger was not submerged and was affected by solar radiation			
BR-3	Teton Dam site	0	6	0	3

[1]A criterion exceedance that occurs on a date when air temperature exceeds 92.3 °C is not considered a violation of Idaho's water quality standards. See text for further explanation